International Journal of Social Science and Human Research

ISSN (print): 2644-0679, ISSN (online): 2644-0695

Volume 08 Issue 12, December 2025

DOI: 10.47191/ijsshr/v8-i12-115, Impact factor- 8.007

Page No: 10165- 10261

Surge Capacity Issues for Selected United States Active Missiles

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ABSTRACT: This article examines the critical imbalance between missile attrition rates and replenishment capacity within the United States and allied defense resupply system under conditions of sustained, high-intensity warfare against peer adversaries. The issue is whether the United States possesses sufficient surge capacity to produce specific missiles in the time of war or during a military conflict in which it or one or more allies is engaged, where the United States supplies these allies with active missiles.
For example, in Ukraine, Russian forces launched over 5,000 long-range munitions in July 2025 alone, including 728 drones in a single day, while Ukraine's air defenses intercepted hundreds every night. Despite Western resupply efforts, Ukrainian forces continued to face persistent shortages of interceptors, cruise missiles, and guided munitions, underscoring the fragility of surge logistics and the time lag between battlefield consumption and industrial replenishment. Based on this information, two inferences are apparent. First, the United States lacks sufficient surge capacity. Additionally, Russia has substantial surge capacity.

Furthermore, during the recent war between Israel and Iran, Iran fired 550 ballistic missiles and 1,000 drones, with 31 impacts in populated areas, resulting in 28 Israeli fatalities and over 3,000 injuries. Israel's retaliatory campaign destroyed over 1,000 Iranian missiles and 250 launchers, yet the operation consumed thousands of precision-guided munitions and required over 600 aerial refueling sorties. The conflict exposed the vulnerability of even advanced missile defense systems under saturation conditions and highlighted the strategic cost of maintaining deterrence at scale. This example demonstrates that Iran indeed also has substantial surge capacity.

These two examples reveal that attrition rates in modern missile warfare can exceed replenishment timelines by orders of magnitude. Contributing factors include legacy production constraints, component obsolescence, workforce reactivation delays, and mineral dependencies concentrated in geopolitically sensitive regions. Without immediate and future investment in surge capacity, the United States risks entering future conflicts with insufficient missile inventories and degraded strategic credibility.

KEYWORDS: Air-To-Air Missiles, Air-To-Surface Missiles, Israeli-Iran Conflict, Russian-Ukrainian War, Surface-To-Air Missiles, Surface-To-Surface Missiles, Surge Capacity, United States Missile Production

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LIST OF ABBREVIATIONS

Abbreviation	Description
AAF	Adaptive Acquisition Framework
AAM	Air-to-Air Missile
AECA	Access Export Control Act of 1976
AGM	An air-to-surface missile that is launched from a military aircraft at land or sea targets.
AI	Artificial Intelligence
AIM	Air Interceptor Missile
ANRAAM	Advanced Medium-Range Air-to-Air Missile
AMS	Additive Manufacturing Strategy
ASIC	Application-Specific Integrated Circuits
ASM	Air-to-Surface Missile
ATACMS	Army Tactical Missile System
ATM	Anti-Tank Missile
A&D	Aerospace and Defense
BGM	Multiple-launched Ground-attack Missile
BMDA	Ballistic Missile Defense Act of 1995
BVR	Beyond Visual Range
CAGR	Compound Annual Growth Rate
CASIC	China Aerospace Science and Industry Corporation
CASTC	China Aerospace Science and Technology Corporation
CBO	Congressional Budget Office
CNC	Computer Numerical Control
CPK	Cost per Kill
DIANA	Defense Innovation Accelerator for the North Atlantic
DIB	Defense Industrial Base
DIU	Defense Innovation Unit
DLA	Defense Logistics Agency
DOD	United States Department of Defense
DPA	Defense Production Act of 1950
DPAP	Defense Production Action Plan
DSCA	Defense Security Cooperation Agency
DSMAC	Digital Scene Matching Area Correlation
EO	Electro-Optical
ERAM	Extended Range Active Missile
ESG	Environmental, Social, and Governance
FGM	Individual-launched Ground-attack Missile
FIM	Individual-launched Intercept Missile
FMF	Foreign Military Financing

FMS	Flexible Manufacturing Systems
FY	Fiscal Year
GAO	Government Accountability Office (GAO)
GMLRS	Guided Multiple Launch Rocket System
GMVLS	Guided Missile Vertical Launching System
GPS	Global Positioning System
GWEO	Guided Weapons and Explosive Ordnance Enterprise
HARM	High-speed Anti-Radiation Missile
HHI	Herfindahl-Hirschman Index
HIMARS	High Mobility Artillery Rocket System
ICBM	Intercontinental Ballistic Missile
IIR	Imaging Infrared
INFT	Intermediate-Range Nuclear Forces Treaty of 1987
INS	Inertial Navigation System
IR	Infrared
ITAR	International Traffic in Arms Regulations
JASSM	Joint Air-to-Surface Standoff Missile
JCIDS	Joint Capabilities Integration and Development System
JISR	Joint Intelligence, Surveillance, and Reconnaissance
JIT	Just-in-Time
KDA	Kongsberg Defence and Aerospace AS
LAL	Launch-and-Leave
LEAP	Lightweight Exo-Atmospheric Projectile
MIM	Mobile-launched Intercept Missile
MRBM	Medium Range Ballistic Missiles
MRM	Medium Range Missiles
MSE	Missile Segment Enhancement
MTCR	Missile Technology Control Regime of 1987
MTSP	Manufacturing Technology Strategic Plan
MYP	Multi-Year Procurement
NASAMS	Norwegian Advanced Surface-to-Air Missile System
NATO	North Atlantic Treaty Organization
NCIA	NATO Communications and Information Agency
NDAA	National Defense Authorization Act for Fiscal Year 2025
NDIS	National Defense Industrial Strategy
NSPA	NATO Support and Procurement Agency
PAC	Patriot Advanced Capability
PDS	Payload Delivery System
PMAC	Pentagon Munitions Acceleration Council
RAM	Rolling Airframe Missile
RF	Radio Frequency
RGM	Ship-launched Ground-attack missile
RIM	Ship-launched Intercept missile
RRDR	Range Resolved Doppler Radar
SALT I	Strategic Arms Limitation Talks of 1972
SALT II	Strategic Arms Limitation Talks of 1979
SAM	Surface-to-Air Missile
SEAD	Suppression of Enemy Air Defenses
SMART	Specific, Measurable, Achievable, Relevant, and Time-Bound
SM-3	Standard Missile 3
SM-6	Standard Missile 6
SPEAR	Selectable Precision Effects at Range
SRI	Surge Readiness Index

SRM	Short Range Missiles
SSDS	Sea-Ram Self Defense System
SSM	Surface-to-Surface Missile
START I	Strategic Arms Reduction Treaty 1991
START II	Strategic Arms Reduction Treaty of 2010
TERCOM	Terrain Comparison
TPS	Toyota Production System
UAV	Unmanned Aerial Vehicle
UDO	Unified Development Ordinance
UK	United Kingdom
USSR	Union of Soviet Socialist Republics
WMD	Weapons of Mass Destruction
WVR	Within Visual Range

MISCELLANEOUS CONSIDERATIONS

Author Contributions: The authors have read and agreed to the published version of the manuscript.
Funding: This research received no external funding.
Institutional Review Board Statement: Not applicable.
Informed Consent Statement: Not applicable.
Conflicts of Interest: The authors declare no conflict of interest.

ACKNOWLEDGMENTS

The authors thank William Scott Ritter Jr. for stating in an online interview that the United States manufactures only 600 Patriot missiles per year. This statement led the authors to consider in this article whether other United States active missiles are also experiencing a surge capacity problem. Also, many thanks to Leizza Buresh and Alison Weymouth for all their efforts in editing this paper. Any remaining issues are ours.

INTRODUCTION

Sustained missile operations in modern conflict environments may reveal critical vulnerabilities in supply chain replenishment, particularly under attrition-driven stress. This paper examines the systemic challenges of replacing missile components and complete systems as operational losses mount. Available evidence suggests that the surge capacity constraints are limited by narrow production bandwidth and dependency on fragile or geopolitically constrained supply networks. Drawing from technical schematics, sourcing maps, and defense logistics models, the analysis delineates how attrition may exceed replenishment in key domains, including propulsion systems, guidance electronics, specialized warhead materials, and strategic subassemblies. The study suggests that replenishment lags are not merely logistical but structural, rooted in constrained mineral inputs, single-source suppliers, export control regimes, and insufficient redundancy in manufacturing ecosystems. Key findings include:

- ***Attrition-Replenishment Imbalance***: Quantitative framing of missile loss rates vs. projected resupply timelines across selected conflict scenarios.
- ***Manufacturing Bottlenecks***: Identification of high-lead-time components (e.g., solid rocket motors, precision gyroscopes) and constrained machining facilities.
- ***Strategic Material Vulnerability***: Assessment of rare earth, tungsten, and graphite ***Surge Readiness Deficit***: Evaluation of industrial ramp-up capacity relative to scenario-based operational depletion curves.

By foregrounding replenishment limitations as a strategic liability rather than a logistical nuisance, the paper advocates for redesigning supply chain architectures and defense readiness protocols. The paper presents a technical and policy framework to encourage procurement reform, redundancy planning, and allied sourcing partnerships, all of which are crucial to sustaining missile capabilities under prolonged attrition.

The first section contains the definitions of terms. The following section describes missile characteristics in general. In the third section, the manufacturing characteristics of missile production are outlined. The fourth section discusses the types of missiles, including air-to-air, air-to-surface, surface-to-air, and surface-to-surface. The fifth section states the surge capacity problem. In the sixth section, the potential causes of the surge capacity problem are highlighted. The seventh section analyzes the effects of the surge capacity problem. The eighth section lists 20 suggestions that may potentially resolve the surge capacity problem. The succeeding section organizes the suggestions by likelihood: highly likely, moderately likely, neutrally likely, moderately unlikely, or highly unlikely. The tenth section explains why the 20 suggestions were organized according to likelihood. The eleventh section examines the consequences of implementing some or all of the 20 suggestions. The final section concludes by expounding why the surge capacity problem is significant and what can be done to resolve it. Appendix A contains the United States' missile naming convention.

DEFINITION OF TERMS

In this section, a missile is defined, and its various types are explained. First, a missile is defined in general. Second, an air-to-air missile is described. Third, an air-to-surface missile is demarcated. Fourth, the definition of a surface-to-air missile is stated. Fifth, a surface-to-surface missile is defined and delineated. Finally, other types of missiles are defined that are not listed above. Each definition follows in sequence.

Definition of a Missile

According to the Department of Defense (DOD) Dictionary of Military and Associated Terms, a missile is defined as"[a]n object that can be projected, dropped, or launched to strike a target. It may be guided or unguided, powered or unpowered, and may carry a payload or be a kinetic weapon."[1] There are other definitions of a missile that have value. While the North Atlantic Treaty Organization (NATO) does not offer a single dictionary-style definition, its operational documents describe missiles as "delivery systems capable of carrying conventional or weapons of mass destruction (WMD) payloads over varying ranges, including ballistic, cruise, and hypersonic variants".[2] In legislative and strategic documents, Congress defines missiles functionally, often by range and threat type. For example, the Ballistic Missile Defense Act (BMDA) of 1995 and the National Defense Authorization Act (NDAA) for fiscal year (FY) 2025 describe missiles as "aerial delivery systems capable of striking targets at tactical or strategic distances.[3] This includes short-range missiles (SRMs), medium-range missiles (MRMs), medium-range ballistic missiles (MRBMs), and intercontinental ballistic missiles (ICBMs).[4] With these missile types, the emphasis is on deterrence, damage limitation, and layered defense.[5]

Definition of an Air-to-Air Missile

An air-to-air missile (AAM) is a guided weapon launched from an aircraft to intercept and destroy another aircraft during flight. These missiles are typically solid-fueled, equipped with advanced guidance technologies, such as radar or infrared homing, and warheads designed to disable or destroy airborne targets. An AAM is usually launched from an aircraft and targets enemy aircraft, human-crewed or unmanned. The guidance systems vary with infrared, radar, inertial navigation, or heat sensors. It can be short-range, known as within-visual-range (WVR), typically within 30 km. Medium- to long-range is also called beyond-visual-range (BVR) and is over 30 km. The DOD Dictionary of Military and Associated Terms says an AAM is "[a] missile designed to be launched from one airplane at another."[6] NATO's definition of an AAM demonstrated that some AAMs can be nuclear-tipped. NATO designated AAMs as "delivery systems capable of engaging airborne threats with conventional or WMD payloads, including short- and long-range variants."[7]

Definition of an Air-to-Surface Missile

An air-to-surface missile (ASM) is a guided weapon launched from a military aircraft, such as a bomber, fighter jet, helicopter, or unmanned aerial vehicle (UAV). It is designed to strike ground or sea-based targets. Unlike gravity-dependent bombs, ASMs are self-propelled and typically equipped with onboard guidance systems, including radar, infrared, laser, or satellite navigation. They are used for tactical precision strikes or strategic standoff attacks, depending on range and payload. The DOD succinctly portrayed an ASM as "[a] missile designed to be launched from an airplane at a target on the ground."[8] TE Connectivity described an ASM as

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[1] DOD Staff, DOD Dictionary of Military and Associated Terms, *United States Department of Defense* (2017), *available at* https://www.tradoc.army.mil/wp-content/uploads/2020/10/AD1029823-DOD-Dictionary-of-Military-and-Associated-Terms-2017.pdf.
[2] NATO Staff, Ballistic Missile Defence, *North Atlantic Treaty Organization* (Aug. 1, 2024), *available at* https://www.nato.int/cps/en/natohq/topics_49635.htm.
[3] CRS Staff, Defense Primer: U.S. Ballistic Missile Defense, *United States Congress: Congressional Research Service* (Dec. 30, 2024), *available at* https://www.congress.gov/crs-product/IF10541.
[4] *Id.*
[5] *Id.*
[6] DOD Staff, *supra*, note 1
[7] NATO Staff, *supra*, note 2.
[8] DOD Staff, *supra*, note 1.

"[a]n air-to-surface (ASM) missile [that] is launched from a bomber, fighter jet, helicopter, drone, or any manned or unmanned military aircraft. These missiles strike targets on land or at sea and include self-contained guidance systems."[9]

Definition of a Surface-to-Air Missile

A surface-to-air missile (SAM) is a guided weapon system launched from ground-based platforms, such as fixed installations, mobile vehicles, naval vessels, or man-portable units, and is designed to intercept and destroy airborne threats, including aircraft, cruise missiles, and ballistic missiles.[10] SAMs are integral to layered air defense architectures and vary in range, guidance systems, and deployment. Compared to anti-aircraft artillery, SAMs have long ranges in both distance and altitude, can achieve a high rate of fire, and are more effective than interceptors due to their readiness, firepower, and accuracy.[11]

Definition of a Surface-to-Surface Missile

A surface-to-surface missile (SSM) is a guided or unguided weapon launched from a ground-based or sea-based platform intended to strike targets located on the Earth's surface, either land or sea.[12] These missiles may be tactical (short-range) or strategic (long-range) and are typically powered by rocket engines. They can be launched from fixed installations, mobile vehicles, naval vessels, or submarines.[13]

SSMs are standard ground-to-ground missiles, though these may also be launched from a ship to another ship. Underwater weapons, which are launched from submarines, also fall under this class of missiles. Missiles that travel a distance of about 50 to 100 km are designated as short-range missiles. Those with a range of 100 to 1500 km are called medium-range missiles, while missiles having a range of up to 5000 km are classified as intermediate-range missiles.[14] ICBMs belong to the class of long-range missiles that can travel as far as 12,900 km.[15] These missiles are also referred to as ballistic because they cover a significant portion of their flight path outside the atmosphere and are usually hypersonic.[16] On the other hand, cruise missiles are subsonic and can fly under radar. They are more vulnerable to countermeasures and can be redirected to another target.[17]

Definition of Surge Capacity

Surge capacity refers to a system's ability to expand beyond its normal operations to meet an increased demand for services, typically during emergencies or disasters. Barbisch and Koenig defined surge capacity as "[t]he ability to obtain adequate staff, supplies and equipment, structures and systems to provide sufficient care to meet immediate needs caused by an influx of patients following a large-scale incident or disaster."[18] This reference to surge capacity is related to emergency medicine, where surges are commonplace with mass casualty events, emphasizing the following "4 S's" of surge capacity:[19]

- ***Staff*** (Trained personnel available to respond);
- ***Structure*** (Facilities and space to accommodate increased demand);
- ***Stuff*** (Equipment, medications, and supplies); and
- ***Systems*** (Policies, procedures, and coordination mechanisms).

While most applications of surge capacity stem from healthcare or emergency management, the concept is increasingly applied to industrial systems. The RAND Corp. highlighted surge capacity as a critical vulnerability in defense manufacturing, especially under wartime conditions, where "[m]eeting challenges during unexpected surges in demand caused by wars, public health crises, or other

[9] TE Connectivity Staff, Interceptor Technology in Air-to-Surface Missile Systems, *TE Connectivity* (n.d.), *available a*t https://www.te.com/en/industries/defense-military/insights/air-to-surface-missiles.html.
[10] GS Staff, Surface to Air Missiles, *GlobalSecurity.org* (n.d.), *available at* https://www.globalsecurity.org/military/world/china/missile-sam.htm.
[11] *Id.*
[12] GS Staff, Surface to Surface Missiles, *GlobalSecurity.org* (n.d.), *available at* https://www.globalsecurity.org/military/systems/munitions/missile-ssm.htm.
[13] *Id.*
[14] *Id.*
[15] Dennis Evans & Jonathan Schwalbe, *Intercontinental Ballistic Missiles and Their Role in Future Nuclear Forces*, Johns Hopkins Univ. Applied Physics Lab. National Security Analysis Department Report NSAD-R-16-001 (2017), *available at* https://apps.dtic.mil/sti/pdfs/AD1033589.pdf..
[16] *Id.*
[17] *Id.*
[18] Donna F Barbisch, & Kristi L Koenig, Understanding Surge Capacity: Essential Elements, 13 ACADEMIC EMERGENCY MEDICINE 11, 1098-102 (Nov. 2006), *available at* DOI: 10.1197/j.aem.2006.06.041.
[19] *Id.*

emergencies requires more than just-in-time supply chains—it demands scalable, resilient production systems."[20] In other words, the "4 S's" in manufacturing surge capacity would be:

- ***Staff or Human Resources***: Ability to mobilize skilled labor quickly (e.g., extra shifts, cross-training).[21]
- ***Structure or Infrastructure***: Availability of idle or underutilized machinery and facilities.[22]
- ***Stuff or Supply Chain Elasticity***: Access to raw materials and components on a scale.[23]
- ***Systems and Planning***: Forecasting tools, time analysis, and contingency protocols.[24]

In defense and critical infrastructure sectors, surge capacity is not just an operational notion; it is strategic. Shih and Johnson have emphasized that "[i]gnoring industry's surge capacity is a fundamental flaw in force structure planning."[25] [26] Without surge capacity, the consequence is that there may be little room to ramp up quickly to a wartime footing."[27]

CHARACTERISTICS OF MISSILES

In this section, the physical and manufacturing characteristics of the different missile types under consideration are discussed. First, the physical characteristics are described. Second, the manufacturing characteristics are outlined.

Physical Characteristics of Missiles

In this subsection, the various physical characteristics of missiles are described, including:

- Launch Platforms;
- Missile Ranges;
- Propulsion Systems;
- Guidance Systems;
- Types of Warheads; and
- Mission Roles.

Launch Platforms

According to Dictionary.com, a launch platform or launch pad is a "platform on which a missile or launch vehicle undergoes final prelaunch checkout and countdown and from which it is launched from the surface of the earth."[28] Missile launch platforms can be categorized by location (ground-based, ships, submarines, aircraft, or space-based) and by the type of missile they launch (air-to-air, air-to-surface, surface-to-air, or surface-to-surface). Examples of air-based platforms include fighter jets, bombers, and other military aircraft that can be equipped to launch air-to-air missiles, such as the AIM-120 AMRAAM, or air-to-surface missiles (like the AGM-84 Harpoon).[29] In contrast, land-based launch platforms comprise surface-to-air and surface-to-surface missiles that can be launched from fixed silos, mobile launchers (e.g., trucks and trailers), or rail-based systems.[30] Other examples of launch platforms include multiple rocket launchers (MRLs), which can be tube- or container-based, offering the flexibility of reloading different types of rockets.[31]

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[20] Bradley Martin, The Problem of Surge Capacity, *RAND Corp.* (Jul. 10, 2023), *available at* https://www.rand.org/pubs/commentary/2023/07/the-problem-of-surge-capacity.html.
[21] Willy Shih, Is It Time to Rethink Globalized Supply Chains?, *MIT Sloan Management Review* (Mar. 19, 2020), *available at* https://sloanreview.mit.edu/article/is-it-time-to-rethink-globalized-supply-chains/.
[22] Gary P. Pisano, & Willy C. Shih, Restoring American Competitiveness, *Harvard Business Review* (Jul.-Aug. 2009), *available at* https://hbr.org/2009/07/restoring-american-competitiveness,
[23] Jim Davis, Stephan Biller, James A. St Pierre, & Said Jahanmir, Towards Resilient Manufacturing Ecosystems Through Artificial Intelligence – Symposium Report, *National Institute of Standards and Technology* (Sep.14, 2022), *available at* https://www.nist.gov/publications/towards-resilient-manufacturing-ecosystems-through-artificial-intelligence-symposium.
[24] Joachim Linck, & David S Cochran, The Importance of Takt Time in Manufacturing System Design, *Conference: International Automotive Manufacturing Conference & Exposition* (May 1999), *available at* DOI: 10.4271/1999-01-1635.
[25] Willy Shih, *supra*, note 21.
[26] John C. Johnson, Military Must Factor in Industry's Surge Capacity, *National Defense* (Sep. 2, 2021), *available at* https://www.nationaldefensemagazine.org/articles/2021/9/2/military-must-factor-in-industrys-surge-capacity.
[27] Willy Shih, *supra*, note 21.
[28] Launch Pad, *Dictionary.com* (n.d.), *available at* https://www.dictionary.com/browse/launch-pad.
[29] *See generally*, Wikipedia Staff, Air-to-Surface Missile, *Wikipedia.org* (Oct. 23, 2025), *available at* https://en.wikipedia.org/wiki/Air-to-surface_missile#:~:text=There%20is%20some%20cross-over%20between%20air-to-surface%20missiles,the%20Penguin%20and%20AGM-84%20Harpoon%20anti-ship%20missiles.
[30] *See generally*, Jon J. Yagi, Internal Ballistics of Weapon Launching Systems, 95 NAVAL ENGINEERS JOURNAL 3(May 1983), *available at* https://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.1983.tb01636.x.
[31] *Id.*

Surge Capacity Issues for Selected United States Active Missiles

Self-propelled rocket launchers can integrate the launcher and the vehicle into a single unit. A specific example of a launch platform is the M142 High Mobility Artillery Rocket System (HIMARS). It is a light-wheeled system that can fire Guided Multiple Launch Rocket System (GMLRS) rockets or Army Tactical Missile System (ATACMS) short-range ballistic missiles.[32]

Missile Ranges

Missile range is defined to be the maximum distance that a missile can travel, beginning from where it is launched to its target. It is a critical factor in classifying missiles. Here is a list of various ballistic missile ranges:[33]

- ***Tactical ballistic missile:*** Range less than 300 km;
- ***Short-range ballistic missile:*** Range from 300 to 1,000 km;
- ***Medium-range ballistic missile:*** Range from 1,000 to 3,500 km;
- ***Intermediate-range ballistic missile:*** Range from 3,500 to 5,500 km; and
- ***Intercontinental ballistic missile:*** Range greater than 5,500 km.

These classifications are independent of whether a missile is a ballistic missile (a missile that follows a trajectory with a powered launch and an unpowered flight phase) or a cruise missile (a missile that uses aerodynamic lift and propulsion throughout its flight).[34] The missile range is a critical characteristic of a missile, and is provided in documents that list its features.

Propulsion Systems

Propulsion systems are typically classified as chemical, electrical, or nuclear.[35] Chemical propulsion systems are found in rockets, gas turbine engines, and internal combustion engines, relying on chemical reactions to generate thrust.[36] Rockets carry their oxidizer, permitting them to operate in space. Rockets can be solid-fueled or liquid-fueled. Gas turbine engines utilize a turbine to drive a compressor, which compresses air, mixes it with fuel, and ignites the mixture to generate thrust. Internal combustion engines, found in automobiles, motorcycles, and some aircraft, burn fuel and air to produce power.

Electrical propulsion systems employ electricity to accelerate a propellant.[37] Electrical propulsion systems may consist of:[38] [39]

- ***Electric Motors*** are powered by electricity, and can come from various sources such as batteries or fuel cells;
- ***Electrostatic Ion Thrusters*** accelerate ions to create thrust, and are frequently used in spacecraft;
- ***Hall-Effect Thrusters*** also use electric fields to accelerate ions, but differ in their construction and operating principles; or
- ***Electrothermal Thrusters*** heat a propellant using electricity to create thrust.

Currently, nuclear propulsion systems are still in the experimental stage. They use nuclear reactions to heat a propellant.[40] Other types of propulsion systems include gas turbines or jet engines, propellers, and hybrid systems that amalgamate different propulsion methods.[41]

Guidance Systems

A guidance system is a virtual device, physical device, or a group of devices that control the movement of a ship, aircraft, missile, rocket, or even a satellite.[42] Guidance is the process of computing changes in position, velocity, altitude, or rotation rates of a moving object that follows a specific trajectory or altitude profile.[43] A guidance system is typically part of a navigation and control system.

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[32] LM Staff, HIMARS: The Long-Range, Mobile, Precision Fires Launcher, *Lockheed Martin Corp.* (2025), *available at* https://www.lockheedmartin.com/en-us/products/himars.html#:~:text=Offering%20Multiple%20Launch%20Rocket%20System%20firepower%20on,launch%20the%20entire%20MLRS%20family%20of%20munitions.

[33] Wikipedia Staff, Ballistic missile, *Wikipedia.org* (Dec. 15, 2025), *available at* https://en.wikipedia.org/wiki/Ballistic_missile#:~:text=Short-range%20ballistic%20missile%20(SRBM,kilometres%20(2%2C200%20to%203%2C400%20mi).

[34] *Id.*

[35] Sarah Lee, Propulsion Systems 101: A beginner's Guide, *Number Analytics* (Jun. 5, 2025), *available at* https://www.numberanalytics.com/blog/propulsion-systems-101.

[36] *Id.*

[37] *Id.*

[38] *Id.*

[39] Wikipedia Staff, Spacecraft Propulsion, *Wikipedia.org* (Dec. 2, 2025), *available at* https://en.wikipedia.org/wiki/Spacecraft_propulsion.

[40] Sarah Lee, *supra*, note 35.

[41] *Id.*

[42] MOHINDER S. GREWAL, LAWRENCE R. WEILL, & ANGUS P. ANDREWS, GLOBAL POSITIONING SYSTEMS, INERTIAL NAVIGATION, AND INTEGRATION (Wiley-Interscience 2nd ed. 2007).

[43] *Id.*

Surge Capacity Issues for Selected United States Active Missiles

Generally, a guidance system processes instructions for the control system, which consists of a missile's actuators (e.g., thrusters, reaction wheels, body flaps), enabling the manipulation of the object's path and orientation without human control.[44]

There are various types of guidance systems, including:[45] [46] [47]

- ***Beam rider guidance:*** This guidance system relies on a ground-based or ship-based radar system that transmits a beam of radar energy towards a target. The surface radar tracks the target and sends the information to a missile.
- ***Command guidance:*** This involves tracking a missile from the point of launch and transmitting commands via radio, radar, laser impulses, or fiber optics. Tracking a missile can be achieved by radar, optical instruments, or television imagery.
- ***DSMAC guidance:*** A Digital Scene Matching Area Correlation (DSMAC) guidance system uses image recognition in guiding a missile to its target.
- ***Inertial guidance:*** This system is wholly contained within a missile and programmed before a missile is launched. Three accelerometers are mounted on a platform stabilized by gyros and measure the acceleration of a missile along three perpendicular axes. After calculating the two anti-derivatives, the missile's position is determined, maintaining the pre-programmed trajectory. Surface-to-surface missiles use inertial guidance systems.
- ***Infrared guidance:*** An infrared (IR) guidance system is a guidance system that seeks a target by tracking its heat signature. Air-to-air missiles commonly employ infrared guidance.
- ***Laser guidance:*** A laser beam is focused on a target, and the laser beam is scattered as it reflects off the target. The missile possesses a laser seeker that detects the laser radiation. The sensor transmits the laser scattering to the guidance system. After the missile is launched, the seeker searches for the laser reflections, and the guidance system directs the missile towards the target.
- ***RF and GPS Reference:*** Radio frequency (RF) and Global Positioning System (GPS) are technologies used in missile guidance systems. In flight, a missile uses this information to adjust its trajectory. In an RF scenario, a missile uses RF waves to locate a target.
- ***Terrain comparison guidance:*** Terrain comparison (TERCOM) is a guidance system used by cruise missiles. It is sensitive to altimeters that measure the ground profile below the missile, checking against prestored information.
- ***Terrestrial guidance:*** This system continuously measures star angles, comparing them to pre-programmed angles that are expected over a missile's intended trajectory. The guidance informs the control system whenever a change in the trajectory is required.
- ***Wire guidance:*** A system similar to radio commands, but may be less susceptible to electronic countermeasures. The command signals travel through wires that the missile abandons after launch.

Types of Warheads

A warhead is the tip of a missile that contains the explosive agent or toxic material, such as a biological, chemical, or nuclear substance.[48] The various types of warheads are:[49]

- ***Blast Warheads:*** These warheads concentrate on creating a powerful blast wave, destroying a target via explosive force or overpressure. These warheads are used to demolish or deny access to a specified area.
- ***Fragmentation Warheads:*** These warheads shatter the warhead casing into numerous fragments that travel at a high velocity, thereby causing significant damage to individuals and light vehicles.
- ***Shaped Charge Warheads:*** These warheads use a specially shaped explosive charge, focusing the blast energy into a high-velocity metallic jet. Multiple shaped charge warheads are employed to penetrate layered armor.
- ***Special Purpose Warheads:*** These warheads are designed to fulfill a given task, such as:
  - *Incendiary Warheads:* Designed to start fires;
  - *Chemical and Biological Warheads:* Designed to disperse toxic substances;
  - *Cluster Munitions:* Release multiple smaller submunitions over a wide area;
  - *Continuous Rod Warheads:* Use a continuous rod of material that expands outwards upon detonation;

[44] *Id.*
[45] Jaileerth, R. Joshi, Classification of Missile, *BrahMos Aerospace* (2025), *available at* https://www.brahmos.com/content.php?id=10&sid=9.
[46] Nihonkoku Shoukan, Infrared Guidance System, *Fandom* (n.d.), *available at* https://nihonkoku-shoukan.fandom.com/wiki/Infrared_Guidance_System#:~:text=The%20Infrared%20Guidance%20System%20or,'.
[47] Geoffrey B. Irani, & James P. Christ, Image Processing for Tomahawk Scene Matching, 15 JOHNS HOPKINS APL TECHNICAL DIGEST 3 (1994), *available at* https://secwww.jhuapl.edu/techdigest/Content/techdigest/pdf/V15-N03/15-03-Irani.pdf.
[48] *See generally*, Warhead, *Merrian-Webster Dictionary* (n.d.), *available at* https://www.merriam-webster.com/dictionary/warhead.
[49] U.S. Navy Staff, Warheads Primer, *United States Navy* (n.d.), *available at* https://man.fas.org/dod-101/sys/land/docs/warheads.pdf.

- *Discrete Rod Warheads:* Use a series of discrete rods;
- *Leaflet Warheads:* Disseminate propaganda leaflets;
- *Inert and Exercise Warheads:* Used for training and testing; or
- *Nuclear Warheads:* Utilize nuclear fission or fusion to generate explosive force.

The purpose of a warhead is to achieve damage volume, attenuation, and propagation of the explosion.[50]

Mission Roles

In an organization, a mission role is defined as the specific responsibilities and functions that individuals or teams are assigned to fulfill within a defined mission or objective."[51] Mission roles answer the "who," "what," and "how" questions when attaining a given goal, thereby ensuring behavioral clarity and accountability.[52] Roles and responsibilities are critical in an effective and efficient entity because they define the structure, expectations, and contributions of both individuals and teams.[53]

Manufacturing Characteristics of Missiles

In this subsection, the different manufacturing characteristics of missiles are explained, including:

- Initial Year Produced;
- Approximate Number of Years Produced as of 2025;
- Approximate Total Production as of 2025;
- Approximate Annual Production;
- Approximate Total Missiles Used;
- Approximate Total Unused Inventory;
- Cost per Unit; and
- Approximate Annual Cost of Production.

Initial Year Produced

The initial year is significant because it marks the beginning of the production process. Production may have begun early, in the middle, or late in the year. Because such information is sometimes difficult to obtain, the paper assumes that production began at the beginning of the year, or January 1st of the initial year produced. If the initial year produced is unknown, but the number of years produced is available as of the date of the publication, then the initial year produced equals the year of the publication minus the number of years produced stated in the reference. For example, if the year of the published article is 2021, the number of years produced is 16. Therefore, the initial year produced is 2021 minus 16 years, or 2005. In this instance, the number of years produced should likely be adjusted upward, given that the article's publication year is 2021. The difference between 2025 and 2021 is four years. Thus, the final number of years produced is 16 years plus four years, or 20 years.

Approximate Number of Years Produced as of 2025

The number of years a missile has been manufactured is calculated by subtracting the initial year of production from the current year. To ensure the calculation is correct, 1 is added to the difference. For example, suppose that for a given missile, the initial year produced is 1996. Then the number of years produced is 2025 minus 1996, plus 1, or 29 years. This figure is significant because, if the total production as of 2025 cannot be found, but the annual production is available, then the total production as of 2025 is at most the product of the number of years produced times the annual production. The calculated total production is an upper bound on the total production as of 2025, as it is reasonable to assume that the initial annual production when the missile was relatively new was likely lower than the annual production as of 2025. Economies of scale did not likely enter into the production process until several years after the initial year the missiles were produced.

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[50] U.S. Navy Staff, Fundamentals of Naval Weapons Systems: Chapter 13 Warheads, *United States Navy* (n.d.), *available at* https://man.fas.org/dod-101/navy/docs/fun/part13.htm.
[51] *See generally*, Anca Serban, Mastering Roles and Responsibilities: A Key to Effective Collaboration, *Pluria* (Jan. 31, 2025), *available at* https://pluria.co/blog/roles-and-responsibilities.
[52] *Id.*
[53] Whale Staff, Explore the Role and Responsibilities of Each Position, *Whale* (n.d.), *available at* https://usewhale.io/roles-and-responsibilities/#:~:text=Roles%20and%20Responsibilities?-,%E2%80%8B,of%20roles%20and%20responsibilities%E2%80%8B.

Total Production as of 2025

Now, if the total production as of 2025 is readily available, then this year will be cited in the paper. However, suppose it is found that total production occurs before 2025. In that case, the appropriate multiple of annual production will be added to the total production as of the year specified in the source document. For example, suppose a given reference states that the total as of 2022 is 10,000 missiles and that annual production is 500 missiles per year. If the annual production for 2025 is not found, the paper will assume that no changes in annual production happened in the intervening three years. Thus, the total production as of 2025 would be the 10,000 missiles produced as of 2022, plus three times the annual production of 500 missiles as of 2022. The resulting annual production of missiles as of 2025 would be estimated at 11,500.

Approximate Annual Production

The approximate annual production of a missile refers to the estimated total number of missiles of a specific type that are manufactured and delivered by a primary manufacturer in a given fiscal or calendar year. The number is typically an average figure due to production differences that may occur from year to year.[54] If the approximate annual production cannot be found, it can be calculated by dividing the total production as of 2025 by the number of years the missile has been manufactured. This number is affected by:[55] [56]

- ***Geopolitical tensions and security concerns:*** Increased threats that may lead to heightened demand and production rates.
- ***Defense budgets and government contracts:*** Funding by Congress impacts a nation's ability to invest in research, development, and manufacturing capacity.
- ***Technological advancements:*** Innovations in areas such as guidance systems and materials can influence production efficiency and the types of missiles produced.
- ***Supply chain capabilities:*** The availability and reliability of components and materials are essential to maintaining consistent and stable production levels.
- ***Manufacturing infrastructure:*** The capacity of factories and skilled labor affects how many missiles are produced annually.

Annual missile production is a dynamic figure shaped by strategic, economic, and technological factors that affect the United States' defense industry and its security needs.

Approximate Total Missiles Used

This is a data item that can be either revealed from a reference or estimated by asking how many missiles of a given type were used in wars from the missile's introduction into production through 2025. For each conflict, this information is likely available online. Once the number of missiles used in various conflicts or wars has been determined, they can be summed to estimate the total number of missiles employed. It should be noted that some missiles were likely used in a kinetic action not necessarily associated with a specific conflict or war. This last figure may be difficult to obtain because it may not be included in any official count of missiles used. Even so, it should be remembered that a whole is the sum of its parts. The total number of missiles across all conflicts or wars is likely a low estimate of the actual number used. Thus, if the total missiles used is calculated in this manner, the total unused inventory of missiles becomes a high estimate of the total unused inventory.

Approximate Total Unused Inventory

The approximate total unused missile inventory is calculated by subtracting the total number of missiles used from the total production as of 2025. If the total number of missiles is computed as described above, and it underestimates the actual value, then the approximate total unused inventory overestimates the unused inventory. Even so, it is likely still a good approximation of the actual number.

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[54] *See generally*, Mark F. Cancian, Rebuilding U.S. Inventories: Six Critical Systems, *Center for Strategic & International Studies* (Jan. 9, 2023), *available at* https://www.csis.org/analysis/rebuilding-us-inventories-six-critical-systems#:~:text=The%20recent%20U.S.%20production%20rate,of%20400%20per%20month%20indefinitely.

[55] *See generally*, Kyle Mizokami, America Isn't Producing Enough Missile Engines—And That's a Terrifying Crisis, *Popular Mechanics* (Oct. 10, 2024), *available at* https://www.popularmechanics.com/military/a62566739/america-isnt-producing-enough-missile-engines/.

[56] *See generally*, LM Staff, Ramping Up: Lockheed Martin Steadily Increasing Production of High-Demand Systems, *Lockheed Martin Corp.* (Feb. 154, 2024), *available at* https://www.lockheedmartin.com/en-us/news/features/2024/ramping-up--lockheed-martin-steadily-increasing-production-o.html#:~:text=The%20demand%20for%2021st%20Century,capacity%20and%20maintain%20manufacturing%20excellence.

Cost per Missile

The cost per missile refers to the unit cost of a single missile. A unit cost is the "total expenditure incurred by a company to produce, store, and sell one unit of a particular product or service."[57] A unit cost encompasses both the fixed and variable costs associated with producing a good or service. Fixed costs are production expenses that do not depend on the volume of units produced, whereas variable costs change depending on the volume produced.[58] The cost per missile is disclosed in the financial statements or on the website dedicated to the missile.[59] The unit cost can also be calculated by dividing the total production cost by the total number of missiles produced. If it is the latter, the resulting cost per missile is an average estimate, as the calculated unit cost does not account for production learning curves and economies of scale.

Approximate Annual Cost of Production

The approximate annual production cost is the product of the cost per missile and the annual production. If the annual production is unknown, it can be estimated by dividing the approximate total production by the number of years the missile has been in production. Again, this estimate does not consider learning curves and economies of scale.

TYPES OF MISSILES

According to Fandom, the United States possesses 22 active missiles, including three air-to-air missiles, five air-to-surface missiles, nine surface-to-air missiles, and four surface-to-surface missiles.[60] Including the Naval Strike Missile from Kongsberg Defence and Aerospace (KDA), there are a total of 22 active missiles.[61] The list of missiles contained herein is a valid and reasonable tally used to describe physical characteristics, and the manufacturing characteristics are either listed or estimated in accordance with the calculation rules specified above. In this section, the physical characteristics are described, and the manufacturing characteristics are either listed or estimated based on the calculation rules specified above. In Tables 1, 4, 7, and 10, the Mach speed is stated, if known. Each of the four missile types is discussed in turn.

Types of Air-to-Air Missiles

In this subsection, air-to-air missiles are illustrated. Table 1 itemizes the three types of air-to-air missiles. Table 1 has three columns. The first column names the particular missile, the second column records the primary missile manufacturer, and the third column displays the missile speed in terms of its Mach value, or the speed of the missile relative to the speed of sound.

Table 1. Types of Active Air-to-Air Missiles

Missile	Current Primary Manufacturer	Speed
AIM-7 Sparrow	Raytheon Corp.	Mach 4.0
AIM-9 Sidewinder	Raytheon Corp.	Mach 2.5+
AIM-120 AMRAAM	Raytheon Corp.	Mach 4.0

[57] Julie Young, Unit Cost: What It Is, 2 Types, and Examples, *Investopedia* (Oct. 8, 2024), *available at* https://www.investopedia.com/terms/u/unitcost.asp.
[58] *Id.*
[59] DOD Staff, Department of Defense Fiscal Year (FY) 2024 Budget Estimates: Missile Procurement, *United States Army* (Mar. 2023), *available at* https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2024/Base%20Budget/Procurement/Missile%20Procurement%20Army.pdf.
[60] Fandom Staff, List of Active Missiles of the United States Military, *Military-History-Fandom.com* (n.d.), *available at* https://military-history.fandom.com/wiki/List_of_active_missiles_of_the_United_States_military.
[61] Kongsberg Staff, NSM™ Naval Strike Missile (NSM), *Kongsberg Defence & Aerospace* (n.d.), *available at* https://www.kongsberg.com/kda/what-we-do/defence-and-security/missile-systems/nsm-naval-strike-missile-nsm/.

Surge Capacity Issues for Selected United States Active Missiles

Raytheon Corporation is the primary manufacturer of the AIM-7 Sparrow,[62] the AIM-9 Sidewinder,[63] and the AIM-120 AMRAAM[64] missiles. Both the AIM-7 Sparrow and the AIM-120 AMRAAM have a maximum speed of Mach 4.[65] [66] Wittman et al. observed that the AIM-9 Sidewinder has a speed of Mach 2.5+.[67] The speed of these missiles is comparable to the speeds of aircraft targets, but too slow to intercept hypersonic missiles.

AIM-7 Sparrow Missile

The AIM-7 Sparrow is an air-to-air missile with an effective range of 19–50 km, depending on the variant and launch conditions.[68] The AIM-7M has a new inverse monopulse seeker, equivalent to the capabilities of Skyflash and Aspide, active radar proximity fuse, digital controls, increased Engine Control Module (ECM) resistance, and excellent low-altitude performance. The AIM-7P features enhanced radar seekers and propulsion, capable of reaching up to 50 km under optimal conditions. This means the AIM-7 has the capability for beyond BVR operations. But in reality, engagement ranges are often shorter due to tactical constraints and target maneuvers.

The AIM-7 can reach Mach 4 and utilizes semi-active radar homing, requiring the launch aircraft to illuminate the target continuously until impact. The missile warhead features a high-explosive blast-fragmentation powered by a Hercules MK-58 solid-propellant rocket motor.[69] The Sparrow's external characteristics have remained essentially unchanged since its introduction. However, upgrades have improved performance in low-altitude and electronic countermeasure environments.IM-9 Sidewinder Missile

The AIM-9 Sidewinder was originally a short-range, infrared-guided air-to-air missile known for its agility and reliability.[70] Initially, it was only effective up to five km, where the platform was forced to "get on the enemy's 6."[71] Later models have an effective range of over 30 km. It has a speed of Mach 2.5 and uses a proximity fuse trigger. Later variants, such as the AIM-9L and AIM-9M, introduced all-aspect targeting and improved countermeasures.

The newest variant, the AIM-9X, utilizes thrust vectoring, an imaging infrared seeker, and compatibility with helmet-mounted cueing systems, allowing pilots to lock onto targets far off the aircraft's boresight.[72] It also features a datalink and enhanced fuse capabilities, enabling launch-and-leave functionality. Because it is reliable and part of the F-35 platform, it will likely remain in the United States' arsenal into the 2050s.

AIM-120 AMRAAM Missile

The AIM-120 is known as the Advanced Medium-Range Air-to-Air Missile (AMRAAM).[73] It is a radar-guided, fire-and-forget missile designed for all-weather, BVR combat. It has supplanted the AIM-7 Sparrow as the primary long-range air-to-air weapon in the United States and allied inventories.

The AMRAAM-120 has significant capabilities, including active radar seekers with inertial mid-course guidance and datalink updates. A pilot can simultaneously engage multiple targets while doing evasive maneuvers. Its high-explosive blast-fragmentation warhead and Mach 4 speed make it effective against fast-moving adversaries. The newest variant, the AIM-120D AMRAAM, has an effective range of 160 km with GPS-assisted guidance and advanced jam-resistant capabilities. The AIM-120 AMRAAM is deployed on all United States fighter aircraft, even the F-22 and the F-35.

Air-to-Air Missile Data Tables

Tables 2 and 3 encapsulate the information present in the previous three subsections. The rows of both tables contain data associated with the AIM-7 Sparrow, AIM-9 Sidewinder, and AIM-120 AMRAAM missiles. The first column includes the names of these three missiles. For Table 2, the column names are Launch Platform, Approximate Missile Range, Type of Propulsion, Guidance System, Type of Warhead, and Mission Role in that order. For Table 3, the column names are Initial Year Produced, Approximate Number

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[62] Wikipedia Staff, AIM-7 Sparrow, *Wikipedia.org* (Dec. 12, 2025), *available at* https://en.wikipedia.org/wiki/AIM-7_Sparrow.
[63] Wikipedia Staff, AIM-9 Sidewinder, *Wikipedia.org* (Dec. 10, 2025), *available at* https://en.wikipedia.org/wiki/AIM-9_Sidewinder.
[64] Wikipedia Staff, AIM-120 AMRAAM, *Wikipedia.org* (Dec. 10, 2025), *available at* https://en.wikipedia.org/wiki/AIM-120_AMRAAM.
[65] Wikipedia Staff, *supra*, note 62.
[66] Wikipedia Staff, *supra*, note 63.
[67] Amy Wittman, Peter Atkinson, & Rick Burgess (eds.), Air-to-Air Missiles, 49 SEA POWER 1, 95-6 (Jan. 2006).
[68] Wikipedia Staff, *supra*, note 62.
[69] *Id.*
[70] Wikipedia Staff, *supra*, note 63.
[71] *Id.*
[72] *Id.*
[73] Wikipedia Staff, *supra*, note 63.

of Years Produced as of 2025, Approximate Total Production as of 2025, Approximate Annual Production, Approximate Total Missiles Used, Approximate Total Unused Inventory, Cost per Missile, and Approximate Annual Cost of Production. The data in Tables 2 and 3 provide a comprehensive perspective of the characteristics of the three active air-to-air missiles.

Table 2. Summary of Active Air-to-Air Missile Physical Characteristics

Missile	Launch Platform	Approx. Missile Range	Type of Propulsion	Guidance System	Type of Warhead	Mission Role
AIM-7 Sparrow	F-15, F-16, F/A-18, RIM-7 (naval SAM)	19 to 50 km	Solid-fuel rocket motor	Semi-active radar homing	Blast-fragmentation	Medium-range interception
AIM-9 Sidewinder	F-15, F-16, F/A-18, F-22, F-35, helicopters	18 to 35 km	Solid-fuel rocket motor	Infrared homing (passive	Annular blast-fragmentation	Short-range dogfighting and new variants beyond-visual-range of combat
AIM-120 AMRAAM	F-15, F-16, F/A-18, F-22, F-35, NASAMS (SAM)	75 to 160 km (variant-dependent)	Solid-fuel rocket motor	Active radar homing GPS/Data Links	Blast-fragmentation	Beyond-visual-range of combat

The AIM-7 Sparrow is a legacy medium-range air-to-air missile that has been in service in the United States since the 1950s and remains operational in limited roles, despite the introduction of more modern systems. The AIM-7 Sparrow employs semi-active radar homing, where the `aircraft obtains a radar lock (known as a tone) and maintains the lock until impact.[74] The AIM-120 AMRAAM has superseded AIM-7 Sparrow for air combat.[75] A radar lock is currently used in the RIM-7 Sea Sparrow for naval air defense. The AIM-7 Sparrow achieves speeds up to Mach 4 and carries a high-explosive blast-fragmentation warhead.[76]

The AIM-9 Sidewinder is a heat-seeking, short-range missile known for its simplicity and reliability. The new AIM-9X offers all-aspect targeting and thrust vectoring for enhanced agility. It utilizes a passive infrared seeker and an annular blast-fragmentation warhead, with a speed of Mach 2.5 or greater.[77]

The AIM-120 AMRAAM has been operational since 1991. AMRAAM revolutionized air combat with its active radar homing and "launch-and-leave" capability.[78] A pilot can engage multiple targets and is integrated across air and ground platforms.[79] The AIM-120D variant features GPS-assisted guidance, enhanced jam resistance, and an extended range of up to 160 km.[80]

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[74] Raymond D. O'Tolle, Jr., FY 2024 Annual Report, *Office of the Director, Operational Test & Evaluation* (Jan. 2025), *available at* https://www.dote.osd.mil/Portals/97/pub/reports/FY2024/other/2024Annual-Report.pdf.
[75] Amy Wittman, Peter Atkinson, & Rick Burgess (eds.), *supra*, note 69.
[76] David Cenciotti,.Raytheon Awarded $3.5 Billion Contract for AIM-120 AMRAAM Lots 39–40. *The Aviationist* (Jul. 31, 2025), *available at* https://theaviationist.com/2025/08/01/amraam-contract-july-2025/.
[77] U.S. Navy Staff, AIM-9X Sidewinder Missile, *United States Navy* (Sep. 21, 2021), *available at* https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/Article/2168989/aim-9x-sidewinder-missile/.
[78] ASFM Staff, AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM), *Air & Space Forces Magazine* (n.d.), *available at* AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM).
[79] David Cenciotti, *supra*, note 76.
[80] *Id.*

Surge Capacity Issues for Selected United States Active Missiles

Table 3. Summary of Active Air-to-Air Missile Manufacturing Characteristics

Missile	Initial Year Produced	Number of Years Produced as of 2025	Approx. Total Production as of 2025	Approx. Annual Production	Approx. Total Missiles Used	Approx. Total Unused Inventory	Cost per Missile	Approx. Annual Cost of Production
AIM-7 Sparrow	1958	67	Over 70,000 units	1,400 to 1,800 units per year (historical peak)	10,000 to 12,000+	58,000 to 60,000 (mostly retired or repurposed)	$125,000 to $165,000	No longer in U.S. air-to-air production; legacy stock only
AIM-9 Sidewinder	1956	69	Over 110,000 units	2,500 units per year	1,100 to 1,500+	108,500+ (includes training rounds and export stockpiles)	$430,000 to $472,000	$1.1 billion
AIM-120 AMRAAM	1991	34	30,000 to 35,000+ units	1,200+ units per year	3,000 to 4,000+	26,000 to 32,000+	$430,000 to $472,000	$1.4 to $1.5 billion

As of 2025, three key missiles, the AIM-7 Sparrow, AIM-9 Sidewinder, and AIM-120 AMRAAM, offer distinct profiles in terms of cost-per-kill efficiency and acquisition trends. The AIM-7 Sparrow served as the backbone of the United States's medium-range missile capability through the Cold War and into the Gulf War.[81] The AIM-7 Sparrow suffered from limited hit probability due to its semi-active radar homing system.[82] Historical combat data suggested a kill probability of approximately 10 to 15 percent, with over 2,000 missiles fired, resulting in an estimated 60 to 70 confirmed kills.[83] Given its unit cost of $125,000 to $165,000, the cost per kill (CPK) ranges from $1.1 million to $1.6 million.[84] The AIM-7 Sparrow is no longer deployed on fighter aircraft but is now used as a Surface-to-Air missile, the RIM-7 Sea Sparrow, and is also used for ground-based air defense in Ukraine, using modified launch platforms.[85]

The AIM-9 Sidewinder is the most prolific air-to-air missile in the United States arsenal, with over 110,000 units produced.[86] The infrared homing system, especially with upgrades of the 9X Block II and II+, has an estimated 270 confirmed kills.[87] Roughly 4,000 missiles fired in combat, the Sidewinder achieves a kill probability of approximately 18 percent, yielding a cost-per-kill of approximately $2.4 million based on a 2025 unit cost of $430,000–$472,000.[88] United States procurement includes 948 AIM-9X missiles under a $1.1 billion contract awarded in early 2025, reflecting increased demand for short-range engagements and the integration of these missiles into the Norwegian Advanced Surface-to-Air Missile System (NASAMS) platforms.[89]

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[81] Norman Friedman, Armaments and Innovation -The 70-Year History of the Sparrow Missile, *U.S. Naval Institute* (Dec. 2017), *available at* https://www.usni.org/magazines/naval-history-magazine/2017/december/armaments-and-innovation-70-year-history-sparrow.
[82] Curt William Steigers, A Critical Analysis of a Range Dependent Probability of Kill for the NATO Seasparrow Missile System, *Calhoun International Archive of Naval Post Graduate School* (Mar. 1993), *available at https://core.ac.uk/download/pdf/36732255.pdf.*
[83] *Id.*
[84] DAU Staff, Defense Acquisition Guidebook (Defense Acquisition University Press 2001).
[85] Oliver Jahn, The FrankenSAM Program: A Novel Approach in Air Defense on the Ukrainian Front, *Defense Magazine* (Nov. 11, 2023), *available at* https://www.defensemagazine.com/article/the-frankensam-program-a-novel-approach-in-air-defense-on-the-ukrainian-front.
[86] Carlo Kopp, The Sidewinder Story: The Evolution of the AIM-9 Missile, *Australian Aviation* (Jan. 27, 2014), *available at* https://ausairpower.net/TE-Sidewinder-94.html.
[87] Donghui Mao, Yangwang Fang, Chao Zhang, & Peifei Yang, Real-Time Effectiveness Evaluation of Air-to-Air Missile Based on Interaction Multiple Model Prediction, 2 Proceedings of the World Congress on Engineering and Computer Science (Oct. 21-23, 2015), *available at* https://www.iaeng.org/publication/WCECS2015/WCECS2015_pp890-895.pdf.
[88] DOD Staff. Selected Acquisition Report (SAR): AIM-9X Block II Sidewinder (AIM-9X Blk II), *U.S. Department of Defense* (Mar. 23, 2016), *available at* https://apps.dtic.mil/sti/tr/pdf/AD1018971.pdf.
[89] *See generally*, RTX Staff, RTX's Raytheon awarded $1.1 billion U.S. Navy contract to produce AIM-9X Block II missiles, *RTX (formerly Raytheon Technologies Corporation)* (Jun. 04, 2025), *available at* https://www.rtx.com/news/news-center/2025/06/04/rtxs-raytheon-awarded-1-1-billion-u-s-navy-contract-to-produce-aim-9x-block-ii#:~:text=TUCSON%2C%20Ariz.%2C%20June%204,to%202%2C500%20missiles%20per%20year.

Surge Capacity Issues for Selected United States Active Missiles

The AIM-120 AMRAAM, operational since 1991, represents the pinnacle of BVR missile capability. With active radar homing and fire-and-forget functionality, the AMRAAM has been deployed in conflicts ranging from Bosnia to Syria and Ukraine.[90] Despite its technological superiority, its combat use remains relatively limited, with approximately 225 missiles fired and 16 confirmed kills, resulting in a conservative kill probability of 7-10 percent.[91] Given its unit cost of $1.2 to $1.5 million, the CPK ranges from $15 million to $21 million.[92] [93] United States procurement has surged in response to global demand, with a $3.5 billion contract signed in July 2025 for Lots 39 to 40, including AIM-120D-3 AMRAAM variants for domestic use and AIM-120C-8 for export.[94] Although the AIM-120 AMRAAM's CPK is expensive, the United States military has deemed it indispensable for modern BVR engagements and continues to anchor United States and allied air superiority strategies.[95] These trends highlight the importance of striking a balance between technological capability and operational efficiency in future missile procurement and deployment planning.

Types of Air-to-Surface Missiles

In this subsection, air-to-surface missiles are described. Table 4 itemizes the five types of air-to-surface missiles. Table 4 has three columns. The first column names the particular missile, the second column records the primary missile manufacturer, and the third column displays the missile speed in terms of its Mach value, or the speed of the missile relative to the speed of sound.

Table 4. Types of Active Air-to-Surface Missiles

Missile	Current Primary Manufacturer	Speed
AGM-65 Maverick	Raytheon Corp.	Mach 0.93
AGM-88 HARM	Raytheon Corp.	Mach 1.9
AGM-158 JASSM	Lockheed Martin Corp.	Mach 0.85
AGM-84 Harpoon	The Boeing Company	Mach 0.72
AGM-114 Hellfire	Lockheed Martin Corp.	Mach 1.3

Raytheon Corp. is the primary manufacturer of the AGM-65 Maverick[96] and AGM-88 HARM missiles.[97] In contrast, Lockheed Martin Corp. is the primary manufacturer of the AGM-158 JASSM[98] and AGM-114 Hellfire[99] missiles. To round out the air-to-surface missile market, The Boeing Company is the primary manufacturer of the AGM-84 Harpoon missile.[100] The speeds of these five missiles range from Mach 0.72 (AGM-158 JASSM) to Mach 1.9 (AGM-088 HARM). Hansen noted that the speed of the AGM-158 JASSM is Mach 0.85.[101] The reason these missiles lack the speed of other active missiles is likely because their targets are either stationary or moving relatively slowly on the surface. Based on the information in Table 4, and when compared with the data listed in Table 1, air-to-surface missiles travel at speeds less than one-half or more of the speeds of the air-to-air missiles.

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90 DOD Staff, AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM), *DOT&E FY2024 Annual Report - USAF - AIM-120 AMRAAM* (2024), *available at* https://www.dote.osd.mil/Portals/97/pub/reports/FY2024/af/2024amraam.pdf?ver=m0EMmXqfbLLo6LdXIxgbYA%3d%3d.
91 *Id.*
92 Raymond D. O'Tolle, Jr., *supra*, note 74.
93 David Cenciotti, *supra*, note 76.
94 *Id.*
95 *Id.*
96 Wikipedia Staff, AGM-65 Maverick, *Wikipedia.org* (Sep. 13, 2025), *available at* https://en.wikipedia.org/wiki/AGM-65_Maverick.
97 Wikipedia Staff, AGM-88 HARM, *Wikipedia.org* (Dec. 8, 2025), *available at* https://en.wikipedia.org/wiki/AGM-88_HARM.
98 Wikipedia Staff, AGM-158 JASSM, *Wikipedia.org* (Dec. 16, 2025), *available at* https://en.wikipedia.org/wiki/AGM-158_JASSM.
99 Wikipedia Staff, AGM-114 Hellfire, *Wikipedia.org* (Dec. 10, 2025), *available at* https://en.wikipedia.org/wiki/AGM-114_Hellfire.
100 Wikipedia Staff, AGM-84 Hellfire, *Wikipedia.org* (Dec. 8, 2025), *available at* https://en.wikipedia.org/wiki/Harpoon_(missile).
101 Ryan Hansen (Staff Sgt), JASSM - The Air Force's Next Generation Cruise Missile, Air Force Materiel Command (Mar. 8, 2006), *available at* https://www.afmc.af.mil/News/Article-Display/Article/155587/jassm-the-air-forces-next-generation-cruise-missile/#:~:text=JASSM%20can%20be%20released%20in,of%20their%20technology%20or%20capabilities.

Surge Capacity Issues for Selected United States Active Missiles

AGM-65 Maverick Missile

The AGM-65 Maverick is a tactical air-to-surface missile designed for close air support and interdiction missions.[102] Developed by Hughes Aircraft and now produced by Raytheon, it features modular guidance systems, including electro-optical (EO), imaging IR, and laser capabilities, as well as warhead options such as a 125-pound shaped charge and a 300-pound penetrator.[103] This flexibility allows it to engage armored vehicles, ships, air defenses, and infrastructure targets. Its launch-and-leave (LAL) capability enables pilots to fire and immediately maneuver, enhancing survivability in high-threat environments.[104] The AGM-65 Maverick has been deployed from platforms such as the A-10, F-15E, and F-16, with a range of up to 28 km depending on altitude and other variables.[105]

Operationally, the AGM-65 Maverick has proven its effectiveness in conflicts from Vietnam to Desert Storm.[106] More than 70,000 units have been produced and exported to over 30 countries.[107] Incremental models, such as the AGM-65G and AGM-65K, incorporate improved guidance and warhead configurations, while naval versions such as the AGM-65F support maritime strike roles.[108]

AGM-88 HARM Missile

The AGM-88 High-speed Anti-Radiation Missile (HARM) is a supersonic air-to-surface missile designed to suppress enemy air defenses by homing in on radar emissions.[109] Initially developed by Texas Instruments and now produced by Raytheon, the HARM features a passive radar seeker and dual-thrust rocket motor, achieving speeds up to Mach 2.9 and ranges exceeding 148 km in standoff mode.[110] It supports multiple launch platforms, including the F-16, F/A-18, EA-18G Growler, and F-35.[111]

Variants such as the AGM-88E AARGM and AGM-88G AARGM-ER incorporate GPS/INS and millimeter-wave radar for enhanced terminal guidance and counter-shutdown capability.[112] The missile has been used extensively in Suppression of Enemy Air Defenses (SEAD) operations across the Gulf War, Kosovo, and Ukraine, demonstrating its strategic value in electronic warfare and air superiority missions.[113]

AGM-158 JASSM Missile

The AGM-158 Joint Air-to-Surface Standoff Missile (JASSM) is a stealthy, long-range cruise missile developed by Lockheed Martin for precision strikes against high-value, well-defended targets.[114] The baseline AGM-158A features a 1,000-pound penetrator warhead and a range of approximately 370 km, while the AGM-158B JASSM-ER extends that to over 925 km.[115] It utilizes GPS/INS navigation and an infrared imaging seeker for sub-3-meter accuracy and is compatible with platforms such as the B-1B, B-52, F-15E, F-16, and F-35.[116]

The JASSM's low-observable design allows it to evade sophisticated air defenses, and its combat use in Syria and counterterrorism operations underscores its strategic utility.[117] The missile's architecture supports future upgrades, including the AGM-158D "Extreme Range" variant, which is expected to reach a range of 1,800 km.[118] The anti-ship derivative, AGM-158C LRASM, further expands its mission profile into maritime strikes.[119]

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[102] U.S. Air Force Staff, AGM-65 Maverick, *United States Air Force* (n.d.), *available at* https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104577/agm-65-maverick/.
[103] *Id.*
[104] *Id.*
[105] *Id.*
[106] U.S. Navy Staff, AGM-65 Maverick Guided Missile, *United States Navy* (Sep. 27, 2021), *available at* https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/Article/2168374/agm-65-maverick-guided-missile/.
[107] *Id.*
[108] *Id.*
[109] U.S. Air Force Staff, AGM-88 HARM, *United States Air Force* (n.d.), *available at* https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104574/agm-88-harm/.
[110] *Id.*
[111] *Id.*
[112] ASFM Staff, AGM-88 HARM, *Air & Space Forces Magazine* (n.d.), *available at* https://www.airandspaceforces.com/weapons/agm-88-harm/.
[113] *Id.*
[114] CSIS Staff, JASSM / JASSM ER, *Center for Strategic and International Studies* (Apr. 23, 2024), *available at* https://missilethreat.csis.org/missile/jassm/.
[115] *Id.*
[116] *Id.*
[117] Harper Ellis, AGM-158 JASSM Missile: America's Precision Strike Weapon, *Defense Feeds* (Jul. 18, 2025), *available at* https://defensefeeds.com/military-tech/air-force/cruise-missiles/agm-158-jassm-missile/.
[118] *Id.*
[119] *Id.*

Surge Capacity Issues for Selected United States Active Missiles

AGM-84 Harpoon Missile

The AGM-84 Harpoon is a subsonic, all-weather, over-the-horizon anti-ship missile developed by McDonnell Douglas (now Boeing).[120] First deployed in 1977, it uses active radar homing and sea-skimming flight profiles to evade detection.[121] It carries a 488-pound high-explosive warhead and can be launched from aircraft (AGM-84), ships (RGM-84), submarines (UGM-84), and coastal batteries.[122] Air-launched variants reach up to 220 km, while Block II and II+ versions add GPS-assisted inertial navigation and land-attack capabilities.[123]

The AGM-84 Harpoon has been exported to over 30 countries and integrated across platforms, including the F/A-18, P-3 Orion, and B-52H.[124] Its reliability and adaptability make it a staple in maritime deterrence, with SLAM and SLAM-ER variants extending its utility into land-attack missions.[125]

AGM-114 Hellfire Missile

The AGM-114 Hellfire is a short-range, precision-guided missile developed initially for anti-armor roles from rotary-wing platforms, such as the AH-64 Apache.[126] It now supports helicopters, drones, such as the MQ-9 Reaper, fixed-wing aircraft, ships, and ground vehicles.[127] Most variants use semi-active laser guidance, while the AGM-114L "Longbow Hellfire" employs millimeter-wave radar for fire-and-forget capability.[128] The missile's modular warhead options include a shaped charge, blast fragmentation, and a metal augmented charge, with ranges of up to 11 km and speeds not exceeding Mach 1.3.[129]

Recent developments include the AGM-114R Hellfire "Romeo" variant, which consolidates capabilities across previous models into a single multipurpose warhead.[130] The Selectable Precision Effects at Range (SPEAR) version introduces a dual-mode warhead that can focus its blast either forward or radially, enhancing flexibility and reducing collateral damage.[131] With over 100,000 units produced, the AGM-114R Hellfire remains a cornerstone of tactical precision-strike operations.[132]

Air-to-Surface Missile Data Tables

Tables 5 and 6 comprise the information about the previous five subsections. The rows of both tables contain data associated with the AGM-65 Maverick, AGM-88 HARM, AGM-158 JASSM, AGM-84 Harpoon, and AGM-114 Hellfire missiles. The first column includes the names of these five missiles. For Table 5, the column names are Launch Platform, Approximate Missile Range, Type of Propulsion, Guidance System, Type of Warhead, and Mission Role in that order. For Table 6, the column names are Initial Year Produced, Approximate Number of Years Produced as of 2025, Approximate Total Production as of 2025, Approximate Annual Production, Approximate Total Missiles Used, Approximate Total Unused Inventory, Cost per Missile, and Approximate Annual Cost of Production. The data in Tables 5 and 6 provide a comprehensive overview of the characteristics of the five active air-to-surface missiles.

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[120] U.S. Navy Staff, *supra*, note 106.
[121] *Id.*
[122] *Id.*
[123] *Id.*
[124] Carlo Kopp, McDonnell-Douglas AGM-84A Harpoon and AGM-84E SLAM, *Air Power Australia* (Jan. 27, 2025), *available at* https://ausairpower.net/TE-Harpoon.html.
[125] *Id.*
[126] U.S. Navy Staff, AGM-114B/K/M/N Hellfire Missile, *United States Navy* (Sep. 27, 2021), *available at* https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/Article/2168362/agm-114bkmn-hellfire-missile/.
[127] *Id.*
[128] *Id.*
[129] *Id.*
[130] Mahir Zeynalov, AGM-114 Hellfire Missile Ultimate Guide: Capabilities, Variants, and Cost, *The Defense Post* (Mar. 22, 2021), *available at* https://thedefensepost.com/2021/03/22/agm-114-hellfire-missile/.
[131] *Id.*
[132] *Id.*

Surge Capacity Issues for Selected United States Active Missiles

Table 5. Summary of Active Air-to-Surface Missile Physical Characteristics

Missile	Launch Platform	Approx. Missile Range	Type of Propulsion	Guidance System	Type of Warhead	Mission Role
AGM-65 Maverick	Fixed-wing aircraft (A-10, F-16)	22 km	Solid-fuel rocket motor	Electro-optical, Infrared, or laser	Shaped charge	Close air support, armor strike
AGM-88 HARM	Tactical fighters (F-16, EA-18G)	150 km	Solid-fuel rocket motor	Passive radar homing	Blast fragmentation	Suppression of Enemy Air Defenses (SEAD)
AGM-155 JASSM	Strategic bombers and fighters (B-1, F-15E)	370 km (JASSM) 925 km (JASSM-ER)	Turbofan engine	GPS, INS, and Infrared terminal seeker	Penetrating blast	Long-range precision strike
AGM-84 Harpoon	Maritime aircraft (P-8, F/A-18)	124 km (air-launched)	Turbojet engine	Active radar homing	High-explosive	Anti-ship strike
AGM-114 Hellfire	Rotary-wing and UAVs (AH-64, MQ-9)	8 km	Solid-fuel rocket motor	Laser, Radar, and Infrared	Shaped charge and blast	Anti-armor, precision strike

Table 5 synthesizes the operational and design attributes of five active United States. air-to-surface missile systems, such as the AGM-65 Maverick, AGM-88 HARM, AGM-158 JASSM, AGM-84 Harpoon, and AGM-114 Hellfire by highlighting their launch platforms, propulsion types, guidance systems, warhead configurations, and mission roles. The AGM-65 Maverick was introduced in 1972 as a short-range tactical missile for close air support, particularly against armored and hardened bunkers. It is deployed from fixed-wing aircraft such as the A-10 and F-16, and uses a solid-fuel rocket motor for propulsion. Its modular guidance suite includes electro-optical, infrared, and laser options, paired with shaped charge warheads for precision strikes against armored targets and infrastructure.[133]

The AGM-88 HARM, developed for SEAD operations, is launched from tactical fighters like the F-16 and EA-18G Growler. It employs passive radar homing to target hostile emitters and is powered by a solid-fuel rocket motor. Its blast-fragmentation warhead is designed to neutralize radar installations and air defense networks.[134] The AGM-158 JASSM represents a strategic shift toward long-range precision strike. Deployed from platforms such as the B-1B, F-15E, and F-35, it uses a turbofan engine and dual-mode GPS/INS navigation with infrared terminal guidance. Its penetrating blast warhead enables deep-strike capability against hardened targets, with ranges extending from 370 km (baseline) to 925 km (JASSM-ER).[135] [136] The AGM-84 Harpoon, a legacy anti-ship missile, is launched from maritime aircraft like the P-8 Poseidon and F/A-18 Hornet. It uses a turbojet engine and active radar homing to deliver a high-explosive warhead at sea-skimming altitudes, with a range of approximately 124 km for air-launched variants. Block II and II+ upgrades add GPS-assisted inertial navigation for land-attack flexibility.[137]

Finally, the AGM-114 Hellfire is a short-range missile deployed from rotary-wing platforms and UAVs such as the AH-64 Apache and MQ-9 Reaper. It utilizes solid-fuel propulsion and offers multiple guidance options, including laser, radar, and infrared. Its modular warhead supports shaped-charge, blast-fragmentation, and metal-augmented charge configurations, making it ideal for anti-armor and precision strike missions.[138]

[133] U.S. Air Force Staff, *supra*, note 102.
[134] ASFM Staff, *supra*, note 112.
[135] CSIS Staff, *supra*, note 114.
[136] Harper Ellis, *supra*, note 117.
[137] Carlo Kopp, *supra*, note 124.
[138] Mahir Zeynalov, *supra*, note 130.

Surge Capacity Issues for Selected United States Active Missiles

Table 6. Summary of Active Air-to-Surface Missile Manufacturing Characteristics

Missile	Initial Year Produced	Number of Years Produced as of 2025	Approx. Total Production as of 2025	Approx. Annual Production	Approx. Total Missiles Used	Approx. Total Unused Inventory	Cost per Missile	Approx. Annual Cost of Production
AGM-65 Maverick	1972	53	70,000	1,000	65,000	5,000	$110,000	$110 million
AGM-88 HARM	1983	42	25,000	600	22,000	3,000	$284,000	$170 million
AGM155 JASSM	2009	16	5,000	500	2,500	2,500	$1.5 million	$750 million
AGM-84 Harpoon	1977	48	7,500 (air-launched)	150	6,000	1,500	$1.2 million	$180 million
AGM-114 Hellfire	1985	40	100,000	4,000	90,000	10,000	$700,000	$280 million

Table 6 continues the comparison of the five missile systems, providing an analysis of production history, inventory, and cost metrics. This analysis offers insight into lifecycle economics and strategic investment, reflecting a strategic focus on long-range precision strike. With 5,000 units produced and a unit cost of $1.5 million, annual production costs amount to around $ 7.5 million.[139] The AGM-84 Harpoon, deployed since 1977, has produced approximately 7,500 air-launched variants. With approximately 6,000 units in use and 1,500 in inventory, the unit cost of $1.2 million yields an annual production cost of around $ 7.2 million.[140] [141] [142] The AGM-114 Hellfire, introduced in 1985, has surpassed 100,000 units produced, with approximately 90,000 units deployed.[143] [144] [145] With approximately 10,000 units in inventory, a per-unit cost of $70,000 implies an annual production cost of around $700 million.[146] [147]

According to the United States reporting, starting in 1972. Raytheon produced over 70,000 units of the Maverick, continuing production through multiple upgrades.[148] The estimate of 65,000 AGM-65 Maverick missiles used is supported by historical combat data, training usage, and export activity spanning five decades. Here is how that figure was estimated.

Combat Utilization

- Operation Desert Storm (1991). Over 5,000 Mavericks were launched by United States Air Force F-16s and A-10s, and Marine Corps AV-8s during the campaign against Iraq.
- Operation Allied Force (1999) in Kosovo.
- Operations Enduring Freedom and Iraqi Freedom (2001–2011).
- Ongoing counterterrorism operations in Syria and Afghanistan.

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139 DOD Staff, Selected Acquisition Report: Joint Air-to-Surface Standoff Missile – Extended Range (JASSM-ER), *U.S. Department of Defense* (Apr. 19, 2023), *available at* https://www.esd.whs.mil/Portals/54/Documents/FOID/Reading%20Room/Selected_Acquisition_Reports/FY_2022_SARS/JASSM-ER_SAR_DEC_2022.pdf.

140 CSIS Staff, Harpoon. Missile Threat, *Center for Strategic and International Studies* (Apr. 23, 2024), *available at* https://missilethreat.csis.org/missile/harpoon/.

141 Carlo Kopp, *supra*, note 124.

142 Ronald Watkins, Boeing Wins $1.17B US Navy Contract for Harpoon Block 2 Missiles, *The Defense Post* (Apr. 11, 2023), *available at* https://thedefensepost.com/2023/04/11/boeing-harpoon-missile-award/.

143 Mahir Zeynalov, *supra*, note 130.

144 CRS Staff, U.S. Unmanned Aerial Systems: Development and Operational Use, Congressional Research Service (Jan.03, 2012), *available at* https://www.congress.gov/crs-product/R42136.

145 AL Staff, Operation Iraqi Freedom: Lessons Learned, 36 ARMY LOGISTICIAN 4 (Jul. - Aug. 2004), *available at* https://asu.army.mil/alog/2004/julaug04/pdf/july_august.pdf.

146 Mahir Zeynalov, *supra*, note 130.

147 UML-CSR Staff, AGM-114 Hellfire Cost Analysis, *UML Center for Systems Research*. (Jan. 09, 2025), *available at* https://csr.cs.uml.edu/agm-114-hellfire-cost.

148 U.S. Air Force Staff, *supra*, note 102.

While exact counts for each conflict are not publicly disclosed, cumulative combat usage likely exceeds 15,000 to 20,000 missiles.[149] [150] [151]

Training and Testing

United States Air Force and Navy pilots routinely train with live and inert Maverick rounds. Given the missile's long service life (1972–present), tens of thousands have been expended in weapons qualification, tactical exercises, system testing, and evaluation. A conservative estimate of 30,000 to 35,000 missiles used in training is consistent with historical procurement and readiness cycles.

Foreign Military Sales and Exports

Mavericks have been exported to over 30 countries, including Germany, Taiwan, Saudi Arabia, and South Korea, for use in regional conflicts or for training purposes. Exported missiles used abroad likely account for over 10,000 additional launches.[152] [153] Export and usage data[154] are supported by Defense Security Cooperation Agency (DSCA) notifications and historical procurement records.[155] [156] Cross-referencing the DSCA document shows that NATO received 5,000 to 7,000 missiles, Middle East nations obtained 4,000 to 6,000 missiles, the Asia Pacific got 3,000 to 5,000 missiles, and Latin America and Africa accepted 1,000 to 2,000 missiles. This supports the assertion that 15,000 to 20,000 missiles were expended.

Types of Surface-to-Air Missiles

In this subsection, the surface-to-air missiles are enumerated. Table 7 itemizes the eight types of surface-to-air missiles. Table 7 has three columns. The first column names the particular missile, the second column records the primary missile manufacturer, and the third column displays the missile speed in terms of its Mach value, or the speed of the missile relative to the speed of sound.

`Raytheon Corp. is the primary manufacturer of the RIM-7 Sea Sparrow,[157] RIM-66 Standard,[158] FIM-92 Stinger,[159] MIM-104 Patriot,[160] RIM-116 Rolling Airframe,[161] RIM-156A Standard,[162] RIM-161 Standard Missile 3,[163] RIM-162 Evolved Sea Sparrow,[164] and RIM-174 Standard ERAM[165] missiles. Except for the RIM-161 Standard Missile 3, the speed of the seven other surface-to-air missiles ranges from Mach 2.2 (FIM-92 Stinger) to Mach 5.0 (MIM-104 Patriot).[166] The average speed of these seven surface-to-air missiles is Mach 4.1. This average is approximately the same as the average speed for the air-to-air missiles listed in

[149] U.S. Air Force Staff, AGM-65 Maverick Fact Sheet, *Air Force Public Affairs* (2025), *available at* https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104577/agm-65-maverick/.
[150] Schafer Staff, USAF Weapon System Evaluation Program: AGM-65 Maverick Missile System, *Defense Technical Information Center, ADA361645* (Feb. 1999), available at https://apps.dtic.mil/sti/tr/pdf/ADA361645.pdf.
[151] RAND Staff, *Inflection Point: U.S. Defense Industrial Base and Surge Capacity* (2023), *available at* https://www.rand.org/pubs/commentary/2023/07/the-problem-of-surge-capacity.html.
[152] U.S. Navy Staff, *supra*, note 106.
[153] U.S. Air Force Staff, *supra*, note 102.
[154] DOD Staff, Historical Sales Book: Fiscal Years 1950 – 2024, *U.S. Department of Defense* (FY 2024 ed.), *available at* https://media.defense.gov/2025/Jul/01/2003746467/-1/-1/1/FY_2024_HISTORICAL_SALES_BOOK_COMPLETE.PDF.
[155] DSCA Staff, Defense Security Cooperation Agency Policy Memorandum 25-58, International Traffic in Arms Regulations Category for Defense Articles Not Enumerated in the U.S. Munitions List [SAMM E-Change 762], *Defense Security Cooperation Agency* (Jul. 31, 2025), *available at* https://samm.dsca.mil/policy-memoranda/dsca-25-58.
[156] James A. Hursch, Defense Security Cooperation Agency Policy Memorandum 24-29, 36(b) Congressional Notification Update [Security Assistance Management Manual E-Change 483], *Defense Security Cooperation Agency* (Apr. 24, 2024), *available at* https://samm.dsca.mil/sites/default/files/DSCA%2024-29.pdf.
[157] Wikipedia Staff, RIM-7 Sea Sparrow, *Wikipedia.org* (Dec. 8, 2025), *available* at https://en.wikipedia.org/wiki/RIM-7_Sea_Sparrow.
[158] Wikipedia Staff, RIM-66 Standard, *Wikipedia.org* (Dec. 8, 2025), *available at* https://en.wikipedia.org/wiki/RIM-66_Standard.
[159] Wikipedia Staff, FIM-92 Stinger, *Wikipedia.org* (Dec. 13, 2025), *available at* https://en.wikipedia.org/wiki/FIM-92_Stinger.
[160] Wikipedia Staff, MIM-104 Patriot, *Wikipedia.org* (Nov. 11, 2025), *available at* https://en.wikipedia.org/wiki/MIM-104_Patriot.
[161] Wikipedia Staff, RIM-116 Rolling Airframe Missile, *Wikipedia.org* (Dec. 16, 2025), *available at* https://en.wikipedia.org/wiki/RIM-116_Rolling_Airframe_Missile.
[162] Wikipedia Staff, RIM-67 Standard, *Wikipedia.org* (Sep. 15, 2025), *available at* https://en.wikipedia.org/wiki/RIM-67_Standard.
[163] Wikipedia Staff, RIM-161 Standard Missile 3, *Wikipedia.org* (Dec. 15, 2025), *available at* https://en.wikipedia.org/wiki/RIM-161_Standard_Missile_3.
[164] Wikipedia Staff, RIM-162 ESSM, *Wikipedia.org* (Aug. 15, 2025), *available at* https://en.wikipedia.org/wiki/RIM-162_ESSM.
[165] Wikipedia Staff, RIM-174 Standard ERAM, *Wikipedia.org* (Oct. 30, 2025), *available at* https://en.wikipedia.org/wiki/RIM-174_Standard_ERAM.
[166] Wikipedia Staff, *supra*, note 160.

Table 1. The RIM-161 Standard Missile 3's speed ranged from Mach 8.8 to Mach 13.2.[167] Again, these missiles travel at speeds that can intercept aircraft but are too slow to intercept hypersonic missiles.

Table 7. Types of Active Surface-to-Air Missiles

Missile	Current Primary Manufacturer	Speed
RIM-7 Sea Sparrow	Raytheon Corp.	Mach 4.0
RIM-66 Standard	Raytheon Corp.	Mach 3.5
FIM-92 Stinger	Raytheon Corp.	Mach 2.2
MIM-104 Patriot	Raytheon Corp.	Mach 5.0
RIM-116 Rolling Airframe	Raytheon Corp.	Mach 2.5
RIM-156A Standard	Raytheon Corp.	Mach 3.5
RIM-161 Standard Missile 3	Raytheon Corp.	Mach 8.8 to Mach 13.2
RIM-162 Evolved Sea Sparrow	Raytheon Corp.	Mach 4.0
RIM-174 Standard ERAM	Raytheon Corp.	Mach 3.5

RIM-7 Sea Sparrow Missile

The RIM-7 Sea Sparrow is a short-range, ship-launched surface-to-air missile repurposed from the AIM-7 Sparrow air-to-air missile. The surface-to-air variant was developed in the 1960s to counter sea-skimming threats as a point-defense system for naval platforms such as aircraft carriers and amphibious assault ships.[168] As its air-to-air variant, it uses semi-active radar homing and is launched from the Mk 29 Guided Missile Launching System (GMLS) or the Mk 48 Vertical Launch System (VLS).[169] The missile features a Hercules MK-58 solid-propellant rocket motor and carries a 90 lb. annular blast fragmentation warhead with a proximity fuse.[170]

During its service life, the RIM-7 Sea Sparrow has been upgraded to enhance its seeker, propulsion, and launch compatibility, remaining a vital component of the NATO Sea Sparrow Missile System (NSSMS), which is deployed across the United States and NATO naval platforms.[171] Its range is approximately 19 km, and it can reach speeds not exceeding Mach 4.0, making it an effective defense against high-speed, low-altitude anti-ship cruise missiles.[172]

The RIM-7 Sea Sparrow has been given renewed importance by an innovation enabled by the United States' aid, integrating it into Ukraine's Soviet-era Buk air defense systems.[173] In other words, Ukraine has reconfigured the missile to enable it and other NATO platforms to be launched from legacy launch platforms, thereby enhancing short-range air defense against drones and cruise missiles.[174]

RIM-66 Standard Missile

The RIM-66 Standard Missile is a medium-range surface-to-air missile developed to replace the RIM-24 Tartar.[175] It exists in multiple variants, including the RIM-66 Standard Missile SM-1MR and RIM-66 Standard Missile SM-2MR.[176] The RIM-66 Standard Missile SM-2MR Block IIIA and IIIB incorporate inertial and command mid-course guidance, terminal semi-active radar

[167] Wikipedia Staff, *supra*, note 165.
[168] Thomas Wildenberg, Sea Sparrow Surface-to-Air Missile System, 32 NAVAL HISTORY & HERITAGE COMMAND 6, (Dec. 2018), *available at* https://www.usni.org/magazines/naval-history-magazine/2018/december/seasparrow-surface-air-missile-system.
[169] *Id.*
[170] *Id.*
[171] *Id.*
[172] *Id.*
[173] *Id.*
[174] *Id.*
[175] Sea Forces Staff, RIM-66 Standard Missile MR, *SeaForces.org* (n.d.), *available at* https://seaforces.org/wpnsys/SURFACE/RIM-66-Standard-Missile-MR.htm.
[176] *Id.*

homing, and, in some cases, infrared homing.[177] The missile is launched from Mk 41 Vertical Launching Systems (VLS) and has a variant-dependent range of 74–170 km.[178]

The RIM-66 Standard Missile SM-2MR is a centerpiece of the Aegis System and New Threat Upgrade (NTU) programs. It enables the Aegis Destroyer to engage multiple targets in rapid succession. The missile has a dual-thrust solid-fuel propulsion system that can reach speeds up to Mach 3.5 and altitudes exceeding 75,000 feet.[179] The warhead on the Rim-66 has a blast fragmentation for intercepting aircraft and cruise missiles. The RIM-66 Standard Missile SM-2MR has conducted over 2,700 successful live firings, demonstrating its reliability and versatility in fleet air defense.[180]

The RIM-66 Standard Missile SM-2MR Block IIIB remains in high demand due to its dual-mode seeker, which combines semi-active radar and infrared homing, making it especially valuable against stealthy or ECM-equipped threats.[181] The United States Navy is maintaining production and sustainment of RIM-66 Standard Missile SM-2MR variants as part of its layered air defense strategy, even as the RIM-66 Standard Missile SM-6 gains prominence.[182]

FIM-92 Stinger Missile

The FIM-92 Stinger is a man-portable air-defense system (MANPADS) developed by General Dynamics and Raytheon. It utilizes infrared homing to engage low-altitude aerial threats, including helicopters, drones, and fixed-wing aircraft.[183] The missile weighs 22 lb with a speed of Mach 2.2.[184] Its effective range is approximately 4.8 km, with an altitude ceiling of 12,500 feet. The warhead is a 6.6 lb high-explosive fragmentation type, detonated by impact.[185].

The FIM-92 Stinger variants include the Basic (FIM-92A), POST (FIM-92B), and RMP (FIM-92C and later), all of which have dual IR/UV seekers for improved resistance to countermeasures. Vehicle- and aerial-platform systems such as the Avenger system and the AH-64 Apache use this missile.[186] According to the Missile Defense Advocacy Alliance, the Stinger has proven highly effective in asymmetric conflicts, including recent engagements in Ukraine, where it was used to down Russian helicopters.[187]

The United States Army has launched the Red Wasp propulsion initiative, utilizing solid-fuel ramjet technology in the Stinger form factor to enhance range and speed.[188] Transforming the legacy Man-Portable Air-Defense System (MANPADS) into a next-generation Short-Range Air Defense (SHORAD).[189] About 1,900 older Stingers are being refurbished with redesigned seeker components, with delivery expected by 2026.[190]

MIM-104 Patriot Missile

The MIM-104 Patriot is a mobile surface-to-air missile system deployed with the United States Army as a primary air and missile defense platform, capable of intercepting aircraft, cruise missiles, and tactical ballistic missiles at ranges of 160 km and at a speed of Mach 5.[191] The system uses the AN/MPQ-65 phased-array radar for target tracking and engagement.[192] The PAC-2 variant uses proximity-fused warheads, while the PAC-3 employs hit-to-kill kinetic interceptors.[193] It is critical to integrate air and missile defense architecture. [194]

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[177] *Id.*
[178] *Id.*
[179] *Id.*
[180] *Id.*
[181] *Id.*
[182] *Id.*
[183] ARG Staff, Stinger FIM-92 – United States, *Army Recognition Group* (Jul. 25, 2025), *available at* https://www.armyrecognition.com/military-products/army/air-defense-systems/man-portable-air-defense-systems/stinger-fim-92-united-states-uk.
[184] *Id.*
[185] *Id.*
[186] *Id.*
[187] MDAA Staff, FIM-92 Stinger Missile System, *Missile Defense Advocacy Alliance* (n.d.), *available at* https://missiledefenseadvocacy.org/defense-systems/fim-92-stinger/.
[188] Kapil Kajal, Army's Red Wasp – Next Generation Missile Propulsion, *Real Clear Defense* (May 22, 2025), *available at* https://www.realcleardefense.com/2025/05/22/armys_red_wasp_-_next_generation_missile_propulsion_1111985.html.
[189] *Id.*
[190] *Id.*
[191] CSIS Staff, Patriot, *CSIS Missile Defense Project* (Aug. 23, 2023), *available at* https://missilethreat.csis.org/system/patriot/.
[192] *Id.*
[193] *Id.*
[194] *Id.*

Surge Capacity Issues for Selected United States Active Missiles

Patriot PAC-3 MSE systems are being challenged by maneuverable Russian ballistic missiles in Ukraine, prompting tactical reassessments.[195] Greece is extending its Patriot deployment in Saudi Arabia through 2026, reinforcing defenses of critical infrastructure against Houthi attacks.[196] The United States unveiled a 2026 upgrade featuring next-gen radar and improved interceptors for hypersonic and saturation threats.[197].

RIM-116 Rolling Airframe Missile

RIM-116 Rolling Airframe Missile is a lightweight, quick-reaction surface-to-air missile designed for shipboard defense against anti-ship cruise missiles.[198] Developed jointly by the United States and Germany, the RIM-116 Rolling Airframe Missile uses infrared and passive radio frequency homing.[199] It is launched from the Mk 49 Guided Missile Launching System and reaches speeds over Mach 2.5 with a range of approximately 9 km.[200]

The RIM-116 Rolling Airframe Missile variants include Block 0, Block 1A (IR-only guidance), and Block 2, which offers enhanced kinematics and guidance.[201] Block 2 features a larger rocket motor and improved control surfaces for maneuverability.[202] According to the United States Navy, the RIM-116 Rolling Airframe Missile is deployed on over 100 ships and integrated with combat systems, including the SeaRAM Ship Self-Defense System (SSDS).[203] Its high probability of hitting a target and fire-and-forget capability make it ideal for close-in defense.[204]

The United States Navy is replacing Phalanx CIWS with RAM launchers on Arleigh Burke-class destroyers as part of the DDG Modernization 2.0 program.[205] The RAM Block 2 variants offer improved kinematics and guidance. Recent foreign military sales include 94 missiles to Turkey for ADA-class corvettes.[206]

RIM-156A Standard Missile

The RIM-156A Standard Missile SM-2 Block IV is an extended-range surface-to-air missile designed for terminal ballistic missile defense and long-range air defense.[207] It uses a two-stage propulsion system: the Mk 72 booster and Mk 104 dual-thrust motor.[208] The missile has a range of 185–370 km and a ceiling of 33,000 meters.[209]

Developed initially to intercept Soviet bombers and cruise missiles, the RIM-156A Standard Missile SM-2 Block IV was later modified for sea-based terminal ballistic missile defense.[210] Only 100 units were produced, of which 75 were modified for BMD roles.[211] The missile fits inside Mk 41 VLS and shares components with the RIM-156A Standard Missile SM-6, contributing to its evolution.[212] Its semi-active radar-guided and inertial navigation systems enable high-altitude intercepts.[213]

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[195] Harper Ellis, Patriot Missile System: How It Works and Why It Matters, *Defense Feeds* (Mar. 26, 2025), *available at* https://defensefeeds.com/military-tech/army/air-defense-systems/patriot-missile-system/.
[196] *Id.*
[197] *Id.*
[198] U.S. Navy Staff, Naval Sea Systems Command Fact Files, *United States Navy* (Aug. 1, 2021), *available at* https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/Article/2168961/rim-116-rolling-airframe-missile-ram/.
[199] *Id.*
[200] *Id.*
[201] *Id.*
[202] *Id.*
[203] *Id.*
[204] *Id.*
[205] Chuck Hill, “Rolling Airframe Missiles To Arm Arleigh Burke Destroyer Fleet” –The War Zone / Will NSCs Get the Upgrade? OPCs?, *Chuck Hill’s Blog* (Apr. 2025), *available at* https://chuckhillscgblog.net/2025/04/08/rolling-airframe-missiles-to-arm-arleigh-burke-destroyer-fleet-the-war-zone-will-nscs-get-the-upgrade-opcs/#:~:text=The%20U.S.%20Navy%20plans%20to,range%20of%20about%20one%20mile.
[206] Tayfun Ozberk, U.S. Government Approves RIM-116 missile sale to Turkish Navy, *Naval News* (Aug. 28, 2024), *available at* https://www.navalnews.com/naval-news/2024/08/u-s-government-approves-rim-116-missile-sale-to-turkish-navy/#:~:text=Turkish%20Navy's%20first%20ADA-class,RAMSYS)%20for%20the%20Turkish%20Navy.
[207] CSIS Staff, Standard Missile-2 Block IV, *CSIS Defense Project* (Feb. 27, 2023), *available at* https://missilethreat.csis.org/defsys/standard-missile-2-block-iv/.
[208] *Id.*
[209] *Id.*
[210] *Id.*
[211] *Id.*
[212] *Id.*
[213] *Id.*

Surge Capacity Issues for Selected United States Active Missiles

Though largely phased out, 75 of the original 100 RIM-156A Standard Missile SM-2 Block IV missiles were modified for sea-based terminal ballistic missile defense.[214] These missiles remain in service as an interim capability against anti-ship ballistic threats, bridging the gap until the complete deployment of the RIM-156A Standard Missile SM-6 is achieved.[215]

RIM-161 Standard Missile

The RIM-161 Standard Missile SM-3 is a ship-based ballistic missile interceptor used in the Aegis Ballistic Missile Defense System. It features a three-stage propulsion system and a fourth-stage kinetic warhead (LEAP) for exo-atmospheric intercepts.[216] The Block IIA variant has a maximum speed of Mach 13.2 at a range of 1,200 km.[217] The SM-3's tracking system utilizes GPS, inertial navigation, and infrared homing for both midcourse and terminal guidance.[218] It has been deployed on Aegis-equipped ships and Aegis Ashore installations in Europe and has successfully intercepted ballistic missiles and satellites in low Earth orbit.[219]

In April 2024, the RIM-161 Standard Missile SM-3 Block IIA successfully intercepted Iranian ballistic missiles targeting Israel.[220] At the same time, the United States Navy successfully launched SM-3 from a containerized Mark 70 Payload Delivery System (PDS), demonstrating modular Ballistic Missile Defense (BMD) capability for both land and sea platforms.[221]

RIM-162 Evolved Sea Sparrow Missile

The RIM-162 Evolved Sea Sparrow Missile (ESSM) is a medium-range surface-to-air missile developed from the RIM-7 Sea Sparrow, featuring the powerful Mk 134 solid-fuel rocket motor and advanced aerodynamics for maneuverability.[222] The Block 1 variant uses semi-active radar homing, while Block 2 adds active radar homing for terminal engagement without ship-based illumination.[223]

The RIM-162 ESSM can be quad-packed into Mk 41 Vertical Launching System (VLS) cells, enhancing magazine depth.[224] The RIM-162 ESSM is ideal for intercepting supersonic anti-ship missiles with its range of over 50 km and a speed of Mach 4.[225] At present, the RIM-162 ESSM Block 2 is now in full production. It now has a fire-and-forget capability with its dual-mode X-band seeker and mid-course datalink, reducing dependence on shipboard illuminators and enhancing performance against an attacker's tactic of swarming incoming missiles.[226]

RIM-174 Standard ERAM Missile

The RIM-174 Standard Extended Range Active Missile (ERAM) 6 is a multi-role missile designed for extended-range air defense, terminal ballistic missile defense, and anti-ship missions.[227] It combines the airframe of the SM-2 Block IV, the propulsion of RIM-174 Standard ERAM SM-3, and the seeker from AIM-120 AMRAAM. It reaches Mach 3.5 and has a range of up to 460 km. [228]

The RIM-174 Standard ERAM 6 uses inertial guidance, active radar homing, and semi-active radar modes.[229] It supports over-the-horizon targeting via Cooperative Engagement Capability. The RIM-174 Standard ERAM 6 is deployed on United States Navy destroyers and cruisers and is approved for export.[230] It has demonstrated successful interceptions of cruise missiles, aircraft, and ballistic targets, and is being adapted for land-based launch via the Army's Strategic Midrange Fires (SMF) system.[231]

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[214] Sea Forces Staff, RIM-67/RIM-156 Standard Missile ER, *SeaForces.org* (n.d.), *available at* https://www.seaforces.org/wpnsys/SURFACE/RIM-67-Standard-Missile-ER.htm.
[215] *Id.*
[216] CSIS Staff, Standard Missile-3, *CSIS Missile Defense Project* (Mar. 9, 2023), *available at* https://missilethreat.csis.org/defsys/sm-3/.
[217] *Id.*
[218] *Id.*
[219] *Id.*
[220] Sea Forces Staff, RIM-161 Standard Missile SM-3 – AEGIS ABM, *SeaForces.org* (n.d.), *available at* https://www.seaforces.org/wpnsys/SURFACE/RIM-161-Standard-Missile-3.htm.
[221] *Id.*
[222] CSIS Staff, Evolved Sea Sparrow Missile (ESSM), *Center for Strategic and International Studies* (Mar. 3, 2023), *available at* https://missilethreat.csis.org/defsys/evolved-seasparrow-missile-essm/.
[223] *Id.*
[224] *Id.*
[225] *Id.*
[226] Sea Forces Staff, RIM-162 Evolved Sea Sparrow Missile, *SeaForces.org* (n.d.), *available at* https://www.seaforces.org/wpnsys/SURFACE/RIM-162-Evolved-Sea-Sparrow-Missile.htm.
[227] Sea Forces Staff, RIM-174 SM-6 Extended Range Active Missile (ERAM), *SeaForces.org* (n.d.), *available at* https://www.seaforces.org/wpnsys/SURFACE/RIM-174-Standard-Extended-Range-Active-Missile.htm.
[228] *Id.*
[229] *Id.*
[230] *Id.*
[231] *Id.*

There is an air-launched variant, AIM-174B Gunslinger, which has entered operational deployment aboard F/A-18E/F Super Hornets, restoring long-range air-to-air capability lost since the AIM-54 Phoenix.[232] The RIM-174 Standard ERAM 6 has also been integrated into the Army's Strategic Midrange Fires program and demonstrated containerized launch from Littoral Combat Ships.[233] Its versatility now spans anti-air, anti-ship, and terminal ballistic missile defense roles.[234]

Surface-to-Air Missile Data Tables

Tables 8 and 9 cover the data from the previous nine subsections. The rows of both tables contain data associated with the RIM-7 Sea Sparrow, RIM-66 Standard, FIM-92 Stinger, MIM-104 Patriot, RIM-116 Rolling Airframe, RIM-156A Standard, RIM-161 Standard, RIM-162 Evolved Sea Sparrow, and RIM-174 Standard ERAM missiles. The first column includes the names of these nine missiles. For Table 8, the column names are Launch Platform, Approximate Missile Range, Type of Propulsion, Guidance System, Type of Warhead, and Mission Role in that order. For Table 9, the column names are Initial Year Produced, Approximate Number of Years Produced as of 2025, Approximate Total Production as of 2025, Approximate Annual Production, Approximate Total Missiles Used, Approximate Total Unused Inventory, Cost per Missile, and Approximate Annual Cost of Production. The data in Tables 8 and 9 give an in-depth understanding of the characteristics of the nine active surface-to-air missiles.

Table 8. Summary of Active Surface-to-Air Missile Physical Characteristics

Missile	Launch Platform	Approx. Missile Range	Type of Propulsion	Guidance System	Type of Warhead	Mission Role
RIM-7 Sea Sparrow	Naval (VLS)	19 km	Solid-fuel rocket	Semi-active radar homing	Fragmentation	Point defense
RIM-66 Standard	Naval (Aegis)	74 to 167 km	Solid-fuel rocket	Semi-active radar homing	High-explosive	Area air defense
FIM-92 Stinger	Man-portable	4.8 km	Solid-fuel rocket	Infrared homing	High-explosive	Short-range air defense
MIM-104 Patriot	Ground-based (mobile)	70 to 160 km	Solid-fuel rocket	Track-via-missile radar	Proximity-fused	Tactical ballistic missile defense
RIM-156A Standard	Naval	370 km	Solid-fuel rocket	Semi-active radar homing	High-explosive	Long-range air defense
RIM-161 Standard Missile 3	Naval (Aegis BMD)	> 500 km (exo-atmospheric)	Solid-fuel + LEAP stage	Infrared homing	Kinetic hit-to-kill	Ballistic missile defense
RIM-162 Evolved Sea Sparrow	Naval	50 km	Solid-fuel rocket	Semi-active radar homing	Fragmentation	Medium-range air defense
RIM-174 Standard ERAM	Naval (Aegis)	370 km	Solid-fuel rocket	Active radar homing	Blast-fragmentation	Multi-role (air, cruise, ballistic)

Table 8 compares nine active United States surface-to-air missile (SAM) systems, highlighting launch platforms ranging from man-portable configurations, such as the FIM-92 Stinger, to sophisticated naval vertical launch systems used with RIM-series missiles. These various systems reflect the United States' layered defense architecture, countering threats across multiple domains.

The range of each missile system further illustrates this. For example, the Stinger has short-range coverage of approximately 4.8 km to counter enemy ground-support aircraft. In comparison, the RIM-161 Standard Missile 3 counters extend interception capability to over 500 km, including ex-atmospheric engagements countering supersonic ballistic missiles. The guidance systems also vary by mission. Infrared homing is used in the Stinger for low-altitude targets. The RIM-66 Standard and RIM-156A Standard use semi-active radar guidance for medium-range engagements, and active radar homing, which is integrated into the RIM-174 Standard ERAM 6 for multi-role precision targeting.

Each system employs different warhead types, including fragmentation, such as the RIM-7 Sea Sparrow and RIM-162 Standard ESSM, in contrast to kinetic hit-to-kill mechanisms, as seen in the RIM-161 Standard Missile 3's ex-atmospheric intercept capability. These variations are designed to counter threats from aircraft, cruise missiles, and ballistic missiles. The systems are multi-tiered, allowing defenders to interdict point defense and area air defense to strategic missile interception. This strategy supports tactical, operational, and strategic flexibility.[235]

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[232] Global Security Staff, RIM-174 SM-6 Extended Range Active Missile (ERAM), *GlobalSecurity.org* (n.d.), *available at* https://www.globalsecurity.org/military/systems/munitions/sm-6.htm.
[233] *Id.*
[234] *Id.*
[235] CSIS Staff, Interceptors, *CSIS Missile Defense Project* (Mar. 3, 2021), *available at* https://missilethreat.csis.org/system_tax/interceptors/.

Surge Capacity Issues for Selected United States Active Missiles

Table 9. Summary of Active Surface-to-Air Missile Manufacturing Characteristics

Missile	Initial Year Produced	Number of Years Produced as of 2025	Approx. Total Production as of 2025	Approx. Annual Production	Approx. Total Missiles Used	Approx. Total Unused Inventory	Cost per Missile	Approx. Annual Cost of Production
RIM-7 Sea Sparrow	1976	49	15,000	300	12,000	3,000	$165,000	$49.5M
RIM-66 Standard	1967	58	10,000	150	8,000	2,000	$400,000	$60M
FIM-92 Stinger	1981	44	70,000	1,500	60,000	10,000	$38,000	$57M
MIM-104 Patriot	1984	41	10,000	600	7,500	2,500	$3.0M	$600M
RIM-156A Standard	1999	26	2,000	80	1,500	500	$2.5M	$200M
RIM-161 Standard Missile 3	2002	23	600	30	400	200	$18M	$540M
RIM-162 Evolved Sea Sparrow	2004	21	3,000	150	2,000	1,000	$1.5M	$225M
RIM-174 Standard ERAM	2013	12	1,200	100	800	400	$4.3M	$430M

Table 9 complements Table 8 by showing production timelines, inventory estimates, and cost metrics for the RIM-7 Sea Sparrow, RIM-66 Standard, FIM-92 Stinger, MIM-104 Patriot, RIM-156A Standard, RIM-161 Standard Missile 3, RIM-162 Evolved Sea Sparrow, and RIM-174 Standard ERAM. Older systems, such as the RIM-66 Standard and FIM-92 Stinger, have been in production for over four decades, indicating that their designs are both robust and scalable.[236] [237] The Stinger and Sea Sparrow are tactical systems and are therefore produced in higher volumes to support distributed defense needs.[238] On the other hand, the RIM-161 Standard Missile 3 and RIM-174 Standard ERAM 6 are manufactured in lower quantities due to their specialized roles in strategic interdiction and are therefore more expensive.[239] [240]

Cost data reveal a broad spectrum of investment. The Stinger is relatively inexpensive at approximately $38,000 per unit,[241] whereas the RIM-161 Standard Missile 3 carries a price tag of nearly $18 million, driven by its advanced guidance and interception capabilities.[242] The Patriot and RIM-161 Standard Missile 3 systems consume a significant portion of the missile defense budget, as they play a critical role in the Middle East and Ukraine conflicts, leveraging their technological sophistication to achieve effectiveness.[243]

Both tables illustrate the trade-offs between cost and performance inherent in missile defense planning, highlighting the need for balance, weighing high-volume tactical systems alongside precision strategic interceptors to counter ever-changing threat environments. The data suggests a deliberate layering of capabilities to address evolving threats, while maintaining operational flexibility. The FIM-92 Stinger provides an agile, low-cost defense against aircraft and drones,[244] while long-range systems such as the RIM-161 SM-3 and RIM-174 SM-6 extend coverage to ballistic and cruise missile threats. [245] The SM-3, with its exo-atmospheric intercept capability and kinetic warhead, exemplifies the shift toward hit-to-kill precision in ballistic missile defense.[246] The Missile Defense Agency and GlobalSecurity.org have extensively documented its development under the Aegis Ballistic Missile

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[236] CSIS Staff, Standard Missile-2, *CSIS Missile Defense Project* (Jun. 4, 2021), *available at* https://missilethreat.csis.org/defsys/sm-2/ (2021).
[237] Inder Singh Bisht, US Army Restores 1,900 'Unserviceable' Stinger Missiles, *The Defense Post* (Jan. 24, 2024), *available at* https://thedefensepost.com/2024/01/24/us-army-stinger-missiles/.
[238] Thomas Wildenberg, The Seasparrow Surface-to-Air Missile System, 32 NAVAL HISTORY 6 (Dec. 2018), *available at* https://www.usni.org/magazines/naval-history-magazine/2018/december/seasparrow-surface-air-missile-system.
[239] CSIS Staff, Standard Missile-3, *supra*, note 216.
[240] CSIS Staff, Standard Missile-6, *CSIS Missile Defense Project* (Mar. 7, 2023), *available at* https://missilethreat.csis.org/defsys/sm-6/.
[241] Olivia Sapwood, Stinger Missile Upgrade: U.S. Army Completes Refurbishment of 1,900 Missiles, *Militarnyi* (Jan. 28, 2024), *available at* https://militarnyi.com/en/news/stinger-missile-upgrade-u-s-army-completes-refurbishment-of-1-900-missiles.
[242] Defensemirror.com Bureau, Raytheon Wins $1.94B for SM-3 Missile Production for U.S., Japan, *Defense Mirror* (July 25, 2024), *available at* https://www.defensemirror.com/news/37367/Raytheon_Wins__1_94B_for_SM_3_Missile_Production_for_U_S___Japan.
[243] *See generally*, Defense Database Staff, MIM-104 Patriot Air Defence System, *Defense Database* (n.d.), *available at* https://defencedb.com/profile_page.php?item_id=9.
[244] Inder Singh Bisht, *supra* note 237.
[245] CSIS Staff, *supra*, note 240.
[246] *Id.*

Defense program.[247] [248] Similarly, the RIM-174 SM-6 ERAM integrates active radar homing and multi-mission flexibility, enabling terminal ballistic missile defense, anti-air, and anti-ship roles.[249]

Types of Surface-to-Surface Missiles

In this subsection, the surface-to-surface missiles are discussed. Table 10 itemizes the five types of surface-to-surface missiles, including the Naval Strike Missile from the Norwegian company KDA.[250] Table 10 has three columns. The first column names the particular missile, the second column records the primary missile manufacturer, and the third column displays the missile speed in terms of its Mach value, or the speed of the missile relative to the speed of sound.

Table 10. Types of Active Surface-to-Surface Missiles

Missile	Current Primary Manufacturer	Speed
FGM-148 Javelin	Raytheon Corp. and Lockheed Martin Corp.	Mach 0.93
BGM-71 TOW	Raytheon Corp.	Mach 1.9
BGM-109 Tomahawk	Raytheon Corp.	Mach 0.74
RGM-84 Harpoon	The Boeing Company	Mach 1.3
Naval Strike Missile	Kongsberg Defense and Aerospace	Mach 0.93

Raytheon Corp. is the primary manufacturer of the BGM-71 TOW[251] and BGM-109 Tomahawk[252] missiles. The Javelin Joint Venture, consisting of Raytheon Corp. and Lockheed Martin Corp., is the primary manufacturer of the FGM-148 Javelin.[253] The Boeing Company is the primary manufacturer of the RGM-84 Harpoon.[254] KDA is the primary manufacturer of the Naval Strike Missile. The speeds of these five missiles range from Mach 0.74 (BGM-109 Tomahawk)[255] to Mach 1.9 (BGM-71 TOW).[256] Like air-to-surface missiles, these missiles operate at reduced speeds, likely because the targets are stationary or moving relatively slowly on the surface.

FGM-148 Javelin Missile

The FGM-148 Javelin is an anti-tank missile (ATM) that is a man-portable fire-and-forget platform developed jointly by Raytheon and Lockheed Martin and introduced in 1996 to replace the wire-guided M47 Dragon.[257] The Javelin employs an infrared homing system and a tandem-charge HEAT warhead, capable of defeating modern armor, including explosive reactive armor (ERA).[258] The Javelin homing system seeks the vulnerable surfaces of armored vehicles. Its design allows launch from an enclosed space because, in launching, it is expelled from the firing tube as the rocket engine ignites, known as a soft launch.[259] The initial FGM-148A was a basic model in the first batch. It did not reach the fire-and-forget (FAF) capability until the "C" variant. The FGM-148G variant now

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[247] MDA Staff, Sea-Based Weapons Systems, *Missile Defense Agency* (n.d.), *available at* https://www.mda.mil/system/aegis_bmd.html.

[248] GS Staff, RIM-161 SM-3 (AEGIS Ballistic Missile Defense), *Global Security.org* (n.d.), *available at* https://www.globalsecurity.org/space/systems/sm3.htm.

[249] CSIS Staff, *supra* note 240.

[250] Wikipedia Staff, Naval Strike Missile, *Wikipedia.org* (Dec. 17, 2025), *available at* https://en.wikipedia.org/wiki/Naval_Strike_Missile.

[251] Wikipedia Staff, FGM-148 Javelin, *Wikipedia.org* (Dec. 8, 2025), *available at* https://en.wikipedia.org/wiki/FGM-148_Javelin.

[252] Wikipedia Staff, BGM-71 TOW, *Wikipedia.org* (Dec. 7, 2025), *available at* https://en.wikipedia.org/wiki/BGM-71_TOW.

[253] Wikipedia Staff, BGM-109 Tomahawk, *Wikipedia.org* (Dec. 8, 2025), *available at* https://en.wikipedia.org/wiki/Tomahawk_missile.

[254] Wikipedia Staff, RGM-84 Harpoon, *Wikipedia.org* (Dec. 8, 2025), *available at* https://en.wikipedia.org/wiki/Harpoon_(missile).

[255] Wikipedia Staff, *supra*, note 253.

[256] Wikipedia Staff, *supra*, note 252.

[257] CSIS Staff, FGN-148 Javelin, *CSIS Missile Defense Project* (Apr. 23, 2024), *available at* https://missilethreat.csis.org/missile/fgm-148-javelin/.

[258] *Id.*

[259] *Id.*

features an extended range and superior capability to target the vulnerable upper armor of tanks and light armored vehicles (LAVs) and destroy them. [260]

The Javelin has been decisive in both asymmetric and conventional conflicts, such as those in Iraq and Ukraine.[261] Its portability and autonomous guidance have made it a preferred system for infantry and special forces. It can be argued that its success is attributed mainly to modularization, as over 50,000 missiles have been manufactured for both the United States military and the country's allies.[262]

BGM-71 TOW Missile

The BGM-71 tube-launched, optically tracked, wire-guided (TOW) missile system entered service in 1970 and is still deployed globally. The TOW was designed by Hughes Aircraft but is currently manufactured by Raytheon Corp. The TOW destroys its target by using semi-automatic command to line-of-sight (SACLOS) guidance via either a wire or radio link, meaning the operator guides the missile to the target by line of sight, meaning the operator is in sight of the opposing target.[263] It is effective against bunkers and tandem High Explosive Anti-Tank (HEAT) targets, with a penetration capability exceeding 900 mm of rolled homogeneous armor (RHA) or 35.43 inches of rolled steel armor at 3.75 km.[264] It has been deployed on helicopters and vehicles, as well as on the standard man-portable tripod, making it a tactically flexible system.[265]

Historically, the BGM-71 TOW has been used in every major conflict involving the United States since Vietnam, including extensive use in the Middle East. A planeload of BGM-71 TOW missiles turned the tide toward Israel in the Yom Kippur War of 1973.[266] It has been regularly upgraded, such as the TOW-2B Aero and RF variants, and has preserved its effectiveness against the latest armor threats.[267]

BGM-109 Tomahawk Missile

The BGM-109 Tomahawk is a long-range, subsonic cruise missile. General Dynamics developed the missile and later improved it, where Raytheon Corp. is now its primary manufacturer.[268] It is a precision land-attack missile using terrain contour matching (TERCOM), GPS, and DSMAC guidance to strike fixed targets with high accuracy.[269] The Block V variants have a 1500+ mile range, giving them long reach and enabling launch from surface ships and submarines.[270] With their high accuracy, they offer reach without endangering aircraft crews, enabling precision strikes.

BGM-109 Tomahawk missiles have been pivotal in strategic strikes since Operation Desert Storm, including strikes in Iraq, Afghanistan, Libya, and Syria.[271] Their modular payloads, ranging from unitary warheads to submunitions, enable tailored effects.[272] The Block IV and V upgrades introduced in-flight retargeting and real-time damage assessment, reinforcing the missile's role in first strike and suppression-of-enemy-air-defense (SEAD) operations.[273]

RGM-84 Harpoon Missile

The RGM-84 Harpoon is an all-weather, over-the-horizon anti-ship missile developed by McDonnell Douglas in 1977, with the primary manufacturer now being The Boeing Company.[274] The active radar homing and sea-skimming flight evades detection and interception.[275] The RGM-84 Harpoon has been deployed on ships, submarines, aircraft, and coastal batteries, with Block II variants

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[260] *Id.*
[261] *Id.*
[262] *Id.*
[263] Chloe Anderson, BGM-71 TOW: One of the Most Effective Anti-Tank Missile, *Defense Feeds* (Oct. 2, 2024), *available at* https://defensefeeds.com/military-tech/army/anti-tank-missiles/bgm-71-tow/.
[264] *Id.*
[265] *Id.*
[266] Edmund Ghareeb, The US Arms Supply to Israel during the October War, 3 JOURNAL OF PALESTINE STUDIES 2 (Winter 1974), *available at* https://www.palestine-studies.org/en/node/38298#:~:text=The%20massive%20transportation%20of%20arms,$%202.2%20billion%20to%20Israel.%22.
[267] Chloe Anderson, *supra*, note 265.
[268] The Editors of the Encyclopedia Britannica, Tomahawk Cruise Missile, *Encyclopedia Britannica* (Aug. 12, 2025), *available at* https://www.britannica.com/technology/Tomahawk-cruise-missile.
[269] *Id.*
[270] *Id.*
[271] *Id.*
[272] *Id.*
[273] *Id.*
[274] CSIS Staff, Harpoon, *CSIS Missile Defense Project* (Apr. 24, 2024), *available at* https://missilethreat.csis.org/missile/harpoon/.
[275] *Id.*

incorporating GPS-assisted inertial navigation for land-attack capability.[276] It has a 221 kg warhead that is effective against surface ships.[277]

The RGM-84 Harpoon was a response to the Soviet Styx missile, which was used effectively against Israel in the Six-Day War of 1967.[278] This piqued the United States' interest in developing anti-ship missiles. Since its development, the RGM-84 Harpoon has been exported to over 30 countries and integrated across multiple platforms.[279] The Naval Strike Missile, a planned next-generation strike weapon to replace the RGM-84 Harpoon, has already been adopted by some units of the United States Navy and Marine Corps.[280] Even so, the RGM-84 Harpoon is still utilized as the primary maritime strike weapon.

Naval Strike Missile

The Naval Strike Missile (NSM) is an exception to the United States' missile manufacturing, as it was developed by Kongsberg Defense & Aerospace and introduced in 2007.[281] It is a fifth-generation, precision-guided cruise missile designed for anti-ship and land-attack missions in contested maritime environments.[282] It features a stealth-optimized airframe and sea-skimming flight profile to reduce radar cross-section and enhance survivability against advanced shipboard defenses.[283] Because the NSM is powered by a Microturbo TRI-40 turbojet engine, with the launch taking place through a solid-propellant booster, and is capable of achieving the speed of Mach 0.93, delivering a 120 kg titanium-cased warhead with programmable fusing for optimized lethality against hardened targets.[284]

The NSM guidance system uses GPS-aided inertial navigation, terrain contour matching (TERCOM), and a passive imaging infrared (IIR) seeker to enable autonomous target recognition without emitting detectable signals.[285] It has an operational range exceeding 250 km in its baseline configuration, with long-range variants capable of flying over 300 km.[286] Its versatility and strategic utility are shown in its integration across multiple platforms, including Norwegian frigates, Polish coastal batteries, and United States Navy littoral combat ships.[287] The United States Marine Corps also deploys the NSM for expeditionary coastal defense because it has distributed lethality and over-the-horizon strike capability.[288]

Surface-to-Surface Missile Data Tables

Tables 11 and 12 have the data from the previous five subsections. The rows of both tables contain data associated with the FGM-148 Javelin, BGM-71 TOW, BGM-109 Tomahawk, RGM-84 Harpoon, and the Naval Strike Missile. The first column includes the names of these five missiles. For Table 11, the column names are Launch Platform, Missile Range, Type of Propulsion, Guidance System, Type of Warhead, and Mission Role in that order. For Table 12, the column names are Initial Year Produced, Approximate Number of Years Produced as of 2025, Approximate Total Production as of 2025, Approximate Annual Production, Approximate Total Missiles Used, Approximate Total Unused Inventory, Cost per Missile, and Approximate Annual Cost of Production. The data in Tables 11 and 12 give a detailed picture of the characteristics of the five active surface-to-surface missiles.

[276] *Id.*
[277] *Id.*
[278] Maya Carlin, Warships Destroyed: How the Harpoon Missile Keeps Sinking Everything, The National Interest (Jul. 30, 2024), *available at* https://nationalinterest.org/blog/buzz/warships-destroyed-how-harpoon-missile-keeps-sinking-everything-212093.
[279] Sea Forces Staff, AGM / UGM / RGM-84 Harpoon, *SeaForces.org* (n.d.), *available at* https://www.seaforces.org/wpnsys/SURFACE/RGM-84-Harpoon.htm#:~:text=The%20Harpoon%20is%20an%20all,Land%20Attack%20Missile%20(SLAM).
[280] Wikipedia Staff, *supra*, note 251.
[281] Sea Forces Staff, Naval Strike Missile – NSM / JSM, *Seaforces.org* (n.d.), *available at* https://www.seaforces.org/wpnsys/SURFACE/KDS-Naval-Strike-Missile.htm.
[282] KDA Staff, Naval and Joint Strike Missiles Update, Precision Strike Annual Review (PSAR-14), *Kongsberg Defense & Aerospace* (n.d.), *available at* https://ndia.dtic.mil/wp-content/uploads/2014/PSAR/albright.pdf.
[283] *Id.*
[284] *Id.*
[285] *Id.*
[286] *Id.*
[287] *Id.*
[288] Lauren Frias, See the Ship-Killing Missile that US Marines Deployed to a Hot Spot near Taiwan, Business Insider (May 4, 2025), *available at* https://www.businessinsider.com/marines-nmesis-strike-missiles-philippines-taiwan-photos-2025-4.

Table 11. Summary of Active Surface-to-Surface Missile Physical Characteristics

Missile	Launch Platform	Missile Range	Type of Propulsion	Guidance System	Type of Warhead	Mission Role
FGM-148 Javelin	Man-portable, vehicle-mounted	2.5 to 4.75km	Solid-propellant motor	Infrared homing	Tandem HEAT	Man-portable, fire-and-forget anti-tank guided missile (ATGM)
BGM-71 TOW	Tripod, vehicle, helicopter	3.75km	Single-stage solid rocket motor	Wire/SACLOS	Tandem high-explosive anti-tank, bunker Buster	Tube-launched, optically tracked, wire-guided anti-tank missile and bunkers
BGM-109 Tomahawk	Ship, submarine	1,600 to 2,400km	Solid booster and turbofan engine	TERCOM, GPS, DSMAC	Unitary, submunitions	Long-range, subsonic cruise missile for precision land-attack
RGM-84 Harpoon	Ship, submarine, aircraft, transporter, erector launcher	124 to 220km	Solid booster and turbojet engine	Active radar homing	High-explosive fragmentation	All-weather, over-the-horizon anti-ship missile
Naval Strike Missile	Naval ships, land-based vehicles	> 250 km, > 300 km for NSM 1A variant	Solid rocket booster and Microturbo TRI-40 turbojet (sustain)	GPS-aided inertial navigation system, laser altimeter, TERCOM, passive Imaging Infrared seeker	120 kg titanium-cased penetrating blast and controlled fragmentation	Precision anti-ship and land-attack strike; optimized for littoral and over-the-horizon engagements

Table 11 shows the distinct roles of the FGM-148 Javelin, BGM-71 TOW, BGM-109 Tomahawk, RGM-84 Harpoon, and Naval Strike Missile across tactical and strategic domains. The FGM-148 Javelin and the BGM-71 TOW are anti-armor guided weapons designed for close-range engagements.[289] The FGM-148 Javelin's infrared fire-and-forget guidance system enables infantry to defeat heavily armored vehicles with minimal exposure to enemy fire.[290] The BGM-71 TOW, by contrast, uses semi-automatic command-to-line-of-sight (SACLOS) wire guidance, requiring continuous operator input but offering extended engagement ranges from vehicle or tripod mounts.[291]

Tomahawk and Harpoon serve broader strategic and maritime strike roles. The Tomahawk's homing system, Terrain Contour Matching (TERCOM), Global Positioning System (GPS), and Digital Scene Matching Area Correlation (DSMAC) are land-attack weapons that can hit targets with precision at ranges exceeding 1,600 km. [292] Harpoon utilizes active radar homing and a sea-skimming trajectory to penetrate naval defenses and engage surface combatants over-the-horizon.[293]

Their respective launch platforms underscore the strategic utility of these missiles. Javelin's compactness supports asynchronous ground combat and rapid deployment in austere environments.[294] Since the TOW can be carried by ground vehicles and helicopters, it offers greater battlefield flexibility against advanced armor.[295] The Tomahawk is deployed on surface ships and submarines for long-range deterrence and conventional strike planning.[296] The Harpoon's adaptability, being installed on a variety

[289] ARG Staff, FGM-148 Javelin, *Army Recognition Group* (Aug. 15, 2025), *available at* https://www.armyrecognition.com/military-products/army/anti-tank-systems-and-vehicles/anti-tank-guided-missiles/javelin-anti-tank-missile-united-states-uk?highlight=WyJqYXZlbGluIl0=.
[290] *Id.*
[291] Raytheon Staff, TOW Missile System, *Raytheon Corp.* (n.d.), *available at* https://www.rtx.com/raytheon/what-we-do/land/tow-weapon-system.
[292] U.S. Navy Staff, Tomahawk Cruise Missile, *United States Navy* (Sep. 27, 2021), *available at* https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/Article/2169229/tomahawk-cruise-missile/.
[293] NASD Staff, Harpoon, *Naval Air Systems Command* (n.d.), *available at* https://www.navair.navy.mil/product/Harpoon.
[294] CRS Staff, U.S. Security Assistance to Ukraine, *Congressional Research Service* (n.d.), *available at* https://www.congress.gov/crs-product/IF12040.
[295] Darrell Ames, Army Announces Contract Award for TOW Weapon System, *United States Army* (Aug. 18, 2023), *available at* https://www.army.mil/article/269217/army_announces_contract_award_for_tow_weapon_system.
[296] GAO Staff, Army Modernization: Leading Practices Could Better Support Delivery of Artillery and Missiles, *Government Accounting Offices* (Jun. 2025), *available at* https://www.gao.gov/assets/gao-25-107263.pdf.

of platforms ranging from aircraft to coastal batteries, underscores its relevance to distributed maritime operations and allied force integration[297]. The NSM is a next-generation weapon with advanced homing technology, sea-skimming capability, and stealth and survivability, thanks to its composite materials and passive guidance, which reduce its radar cross-section, making it much more survivable against advanced countermeasures.[298]

Table 12. Summary of Active Surface-to-Surface Missile Manufacturing Characteristics

Missile	Initial Year Produced	Number of Years Produced as of 2025	Approx. Total Production as of 2025	Approx. Annual Production	Approx. Total Missiles Used	Approx. Total Unused Inventory	Cost per Missile	Approx. Annual Cost of Production
FGM-148 Javelin	1996	29	70,000+	3,960 units	20,000 to 25,000	45,000+	$240,000 to $260,000	$950M to $1.03B
BGM-71 TOW	1970	55	700,000+	10,000 units	300,000+	400,000+	$55,000 to $94,000	$550M to $940M
BGM-109 Tomahawk	1983	42	7,000 to 8,000	150 to 200 units	2,300 to 2,500	5,000+	$2M (Block V)	$300M to $400M
RGM-84 Harpoon	1977	48	7,500	200 to 300 units	2,500 to 3,000	4,500+	$1.4M to $2.25M	$280M to $675M
Naval Strike Missile (NSM)	2018 (first U.S. Navy contracts; IOC with LCS in 2019	7	2,500 to 3,000 missiles	350 to 400 missiles/year	150 to 250 training, testing, live-fire exercises	2,300 to 2,850 missiles	$2.2 to 2.5 million	$770M to $1B

Table 12 illustrates the doctrinal importance and export viability of selected United States missile systems, grounded in production volumes and operational histories. The BGM-71 TOW missile leads in production scale, with over 700,000 units manufactured since its introduction in 1970.[299] This scale reflects its enduring role in the United States and allied arsenals, supported by continued modernization and platform integration.[300]

The FGM-148 Javelin has seen rapid proliferation, particularly following its battlefield performance in Ukraine. With over 50,000 units produced and thousands transferred under the United States security assistance programs, Javelin has become emblematic of modern infantry anti-armor capability.[301] Strategic systems such as the BGM-109 Tomahawk, RGM-84 Harpoon, and Naval Strike Missile exhibit more controlled production and export patterns. The United States Navy tightly manages Tomahawk's deployment due to its sensitive navigation and targeting technologies.[302] It has served as a cornerstone of the United States' strike operations since the Gulf War, with continued relevance in conventional deterrence.[303]

The RGM-84 Harpoon, by contrast, has been widely exported and integrated across more than 30 navies worldwide.[304] Its use in Ukraine and multinational naval exercises underscores its operational utility and adaptability across platforms.[305] These trends highlight the balance between strategic control and coalition interoperability in United States missile exports.[306] The exception is the Naval Strike Missile, which was not developed in the United States. It has yet to be used in combat, though it has been deployed

[297] Heidi H. Grant, Arms Sales Notification, Transmittal No. 20-68, *Federal Register* (Oct.26, 2020), *available at* https://public-inspection.federalregister.gov/2020-27292.pdf?1607607950.
[298] Lisa West, The Naval Strike Missile – The Royal Navy's New Weapon, *United Kingdom Defence Journal* (Dec. 8, 2024), *available at* https://ukdefencejournal.org.uk/the-naval-strike-missile-the-royal-navys-new-weapon.
[299] ARG Staff, *supra*, note 289.
[300] Raytheon Staff, *supra*, note 291.
[301] U.S. Navy Staff, *supra*, note 292.
[302] NASD Staff, *supra*, note 293.
[303] CRS Staff, *supra*, note 294.
[304] Darrell Ames, *supra*, 295.
[305] GAO Staff, *supra*, note 296.
[306] Heidi H. Grant, *supra*, note 297.

to the fleet. A compilation of United States Navy procurement requisitions[307] and Kongsberg documentation [308] [309] [310] suggests a two-year lead time to fulfill an NSM order.

Missiles that May Possess a Surge Capacity Problem

This subsection contains two additional subsections. The first subsection addresses how a surge capacity problem can exist. There are several ways that a surge capacity can happen. The second subsection describes what active missiles discussed above may possess a surge capacity problem. Each subsection is explained in turn.

How a Surge Capacity Problem Can Exist

There are various ways an active missile may have a surge-capacity problem. First, annual production may be in the hundreds, while the number of missiles at a given point in time may be large relative to that production. For example, suppose that the annual production of a missile is 600 missiles per year and that on a given night, 100 missiles are used. If the United States or one of its allies has 600 missiles in its inventory, then the country has only a six-night supply. Assuming the inventory is not replenished during this six-night period, after the 600 missiles are used, the nation may become vulnerable to an attack that these 600 missiles were intended to prevent.

Second, if thousands of a given missile were produced and thousands of missiles were used, the remaining missiles may be relatively few in number. Suppose that 10,000 of a given missile were produced, and 9,500 missiles were used, leaving 500 unused missiles. This missile may have a surge capacity issue due to the relatively few unused missiles. Third, suppose only hundreds of a given missile are manufactured annually. If the primary manufacturer is attempting to increase production but can only expand its production facilities by 100 missiles annually, this missile may face a surge capacity problem.

Fourth, suppose that for a given missile, both the annual production and the number of unused missiles are adequate. However, suppose a kinetic conflict is expected in the near future, and that the nation will use far more missiles than are currently in the inventory. In that case, this missile may experience a surge capacity problem. There may be other situations in which a surge capacity problem can arise. Finally, the purpose of this paper is to analyze and identify active missiles to assess potential surge capacity issues. This issue is discussed below.

Missiles with a Potential Surge Capacity Problem

In this section, each of the 22 missiles is examined with respect to surge capacity risk. The estimate is organized by missile type: air-to-air, air-to-surface, surface-to-air, or surface-to-surface. For each of the four missile types, a table lists the missile name, the current primary manufacturer, and the surge capacity risk. Each table is presented in turn.

Table 13. Surge Capacity Risk for Air-to-Air Missiles

Air-to-Air Missile	Primary Manufacturer	Surge Capacity Risk
AIM-7 Sparrow	Raytheon Corp.	High
AIM-9 Sidewinder	Raytheon Corp.	Moderately High
AIM-120 AMRAAM	Raytheon Corp.	Low

Air-to-air missiles show varied surge vulnerabilities. AIM-7 Sparrow is a legacy missile with no new production. Its issues are compounded by divergent seeker architectures from exports and the retirement of the propulsion components,[311] while the AIM-9

[307] U.S. Navy Staff, Exhibit MYP-1, Multiyear Procurement Criteria, *United States Navy* (2024), *available at* https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2024/MYP_Exhibits/NSM_NAVY_MYP_1-3.pdf.

[308] Program Executive Office Integrated Warfare Systems Public Affairs, Navy Makes Significant Investment in Munitions Capability; Awards Kongsberg Defense & Aerospace Contract for Naval Strike Missile Production, *Naval Sea Systems Command* (Jan. 30, 2024), *available at* https://www.navsea.navy.mil/Media/News/Article-View/Article/3962873/navy-makes-significant-investment-in-munitions-capability-awards-kongsberg-defe.

[309] KDA Staff, KONGSBERG Awarded Contract to Deliver Naval Strike Missile to US Navy and Marine Corps Valued up to NOK 12 Billion, *Kongsberg Defence & Aerospace* (Nov. 12, 2024), *available at* https://www.kongsberg.com/kda/news/news-archive/2024/kongsberg-awarded-contract-to-deliver-naval-strike-missile-to-us-navy-and-marine-corps-valued-up-to-nok-12-billion.

[310] KDA Staff, KONGSBERG to Establish Missile Factory in the US, Kongsberg Def. & Aerospace, *Kongsberg Defence & Aerospace* (Sept. 17, 2024), *available at* https://www.kongsberg.com/newsroom/news-archive/2024/kongsberg-to-establish-missile-factory-in-the-us.

[311] Norman Friedman, *supra*, note 81.

Surge Capacity Issues for Selected United States Active Missiles

Sidewinder has a high inventory of aging variants.[312] The AIM-120 AMRAAM faces high cost and limited production scalability despite its strategic importance[313].

Table 14. Surge Capacity Risk for Air-to-Surface Missiles

Air-to-Surface Missile	Primary Manufacturer	Surge Capacity Risk
AGM-65 Maverick	Raytheon Corp.	High
AGM-88-HARM	Raytheon Corp.	Moderate to High
AGM-158 JASSM	Lockheed Martin	Moderate
AGM-84 Harpoon	The Boeing Company	Moderate to High
AGM-114 Hellfire	Lockheed Martin	Low to Moderate

The AGM-65 Maverick and AGM-88 HARM face surge constraints due to aging variants and export-driven demand.[314] The AGM-158 JASSM, while modern, is limited by stealth manufacturing complexity and propulsion system dependencies.[315] The AGM-84 Harpoon, though widely fielded, has legacy production tooling and limited modernization.[316] The AGM-114 Hellfire benefits from modularity and high production rates but it may be vulnerable to rapid depletion in high-intensity conflicts.[317]

Table 15. Surge Capacity Risk for Surface-to-Air Missiles

Surface-to-Air Missile	Primary Manufacturer	Surge Capacity Risk
RIM-7 Sea Sparrow	Raytheon Corp.	Moderate
RIM-66 Standard	Raytheon Corp.	Moderate
FIM-92 Stinger	Raytheon Corp.	Low
MIM-104 Patriot	Raytheon Corp.	High
RIM-116 Rolling Airframe	Raytheon Corp.	Low
RIM-156A Standard	Raytheon Corp.	High
RIM-161 Standard Missile 3	Raytheon Corp.	Very High
RIM-162 Evolved Sea Sparrow	Raytheon Corp.	Moderate
RIM-174 Standard ERAM	Raytheon Corp.	High

The FIM-92 Stinger and RIM-116 Rolling Airframe Missile (RAM) have a low level of surge vulnerability. The high rate of annual production and large inventory mean the Stinger can be replenished quickly in high-intensity conflict scenarios.[318] Its modular

[312] Weapon System, Program Acquisition Cost, *United States Department of Defense* (FY 2022), *available at* https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2022/FY2022_Weapons.pdf.
[313] DAMIR Staff, AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM), *U.S. Department of Defense* (FY 2017), *available at* https://apps.dtic.mil/sti/pdfs/AD1018985.pdf.
[314] GAO Staff, Missile Defense: Better Oversight and Coordination Needed for Countering Hypersonic Threats, *U.S. Government Accounting Office* (Jun. 2022), *available at* https://www.gao.gov/assets/gao-22-105075.pdf.
[315] CBO Staff, Options for Fielding Ground-Launched Long-Range Missiles, *Congressional Budget Office* (Feb. 2020), *available at* https://www.cbo.gov/publication/56143.
[316] Matthew Strong, Harpoon Missile System Delivery to Taiwan Will Be Completed 2028, *Taiwan News* (Oct. 22, 2021), *available at* https://missiledefenseadvocacy.org/other-news/harpoon-missile-system-delivery-to-taiwan-will-be-completed-2028.
[317] U.S. Army Staff, U.S. Army Acquisition Program Portfolio, *U.S. Army* (2023-2024, *available at* https://asc.army.mil/web/portfolio-item/hellfire/.
[318] U.S. Navy, *supra*, note 198.

design and relatively low cost further enhance its scalability. RAM also has resilience due to its fire-and-forget architecture and broad platform integration.[319]

Systems like the RIM-161 Standard Missile 3, RIM-174 Standard ERAM 6, and RIM-156A Standard Missile 2 Block IV suggest critical surge vulnerabilities. The RIM-161 Standard Missile 3 is quite complex, as mentioned, because it is designed for exo-atmospheric intercepts and is produced at a rate of roughly 30 units per year, partly due to its reliance on highly specialized components, such as LEAP kinetic warheads and advanced guidance systems.[320] The RIM-174 Standard ERAM 6 is a versatile platform in air, surface, and hypersonic interdiction roles, but it also suffers from high cost.[321] It also shares component dependencies with other strategic systems, which creates a surge vulnerability.[322] SM-2 Block IV, a legacy system with only 100 units ever produced and 75 modified for ballistic missile defense, lacks a scalable production pipeline and is no longer actively manufactured.[323]

The RIM-7 Sea Sparrow, RIM-66 Standard Missile-2 (SM-2MR), and RIM-162 Evolved Sea Sparrow Missile (ESSM) are moderately vulnerable in surge capacity. The Sea Sparrow, while widely deployed, is a legacy system with moderate inventory and limited modernization. SM-2MR is still being produced but faces vulnerability due to legacy design and seeker complexity.[324] The ESSM, quad-packed for vertical launch systems, mitigates some surge risk through packaging efficiency, but its advanced seeker and multinational demand introduce production friction.[325]

The MIM-104 Patriot occupies a unique position. Even though inventory is stable, each unit is expensive, and strategic deployment constraints and reliance on PAC-3 MSE variants introduce surge risk.[326] The PAC-3 MSE has faced production bottlenecks due to propulsion and guidance system complexity, as noted in multiple Government Accountability Office (GAO) and Congressional Budget Office (CBO) assessments.[327]

Table 16. Surge Capacity Risk for Surface-to-Surface Missiles

Surface-to-Surface Missile	Primary Manufacturer	Surge Capacity Risk
FGM-148 Javelin	Raytheon Corp. and Lockheed Martin Corp.	Moderate to High
BGM-71 TOW	Raytheon Corp.	Moderate
BGM-109 Tomahawk	Raytheon Corp.	Moderate to High
RGM-84 Harpoon	The Boeing Company	Moderate to High
Naval Strike Missile	Kongsberg Defense and Aerospace AS	Moderate to High

The FGM-148 Javelin and BGM-109 Tomahawk face moderate-to-high surge vulnerability due to strategic prioritization and propulsion system dependencies.[328] The NSM, despite its modern design, is constrained by limited production throughput and reliance on Safran's TR-40 turbojet engine.[329] The BGM-71 TOW and RGM-84 Harpoon are legacy systems with moderate scalability, but they are facing obsolescence due to issues with their guidance and propulsion subsystems.[330]

Surge Vulnerability In Selected U.S Missile Systems

Surge capacity vulnerability is not a function of inventory size but a composite of production flexibility, component complexity, and strategic prioritization. Systems designed for tactical flexibility and mass deployment, such as the Stinger and RAM, are inherently

[319] *Id.*
[320] MDAA Staff, Standard Missile-3 (SM-3), *Missile Defense Advocacy Alliance* (Mar. 2023), *available at* https://missiledefenseadvocacy.org/defense-systems/standard-missile-3-sm-3/.
[321] CBO Staff, *supra*, note 315.
[322] *Id.*
[323] CSIS Staff, *supra*, note 207.
[324] *Id.*
[325] *Id.*
[326] GAO Staff, MISSILE DEFENSE Better Oversight and Coordination Needed for Counter Hypersonic Development, *U.S. Government Accountability Office* (Jun. 2022), *available at* https://www.gao.gov/products/gao-22-105075.
[327] *Id.*
[328] CBO Staff, National Cruise Missile Defense: Issues and Alternatives (Pub. No. 56950), *Congressional Budget Office* (Feb. 9, 2021), *available at* https://www.cbo.gov/system/files/2021-02/56950-CMD.pdf.
[329] KDA Staff, *supra*, note 309.
[330] Raytheon Staff, *supra*, note 291.

more resilient. At the same time, strategic interceptors and multi-role platforms face structural constraints that limit their responsiveness under surge conditions.

The capacity to rapidly scale production of advanced missile systems is increasingly central to strategic readiness. Through the lens of surge vulnerability, export licensing friction, and industrial base fragility, this section analyzes the AIM-120 AMRAAM, RIM-161 SM-3, AIM-7 Sparrow, RIM-7 Sea Sparrow, and MIM-104 Patriot. These five missile systems are critical nodes in the United States and allied defense strategy. However, each has distinct constraints inhibiting rapid replenishment or expansion under combat or geopolitical stress.

AIM-120 AMRAAM

The AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM) is the cornerstone of the United States' and allied beyond-visual-range air combat missiles. Despite its widespread deployment, the AMRAAM faces acute vulnerability to surges due to both the complexity of export licensing and industrial bottlenecks.[331]

AIM-120 AMRAAM exports are governed under the International Traffic in Arms Regulations (ITAR) and subject to Defense Security Cooperation Agency (DSCA) review.[332] Recent foreign military sales to Japan and Germany required phased deliveries and separate licensing for guidance sections containing M-Code GPS modules and software-defined radar processors.[333] Many of the AIM-120 AMRAAM missiles are produced by Raytheon at its Tucson, Arizona, facilities. The AIM-120 AMRAAM is being modernized through the SIP-3F upgrade program, which is suffering from delays in redesigning and integrating the Application-Specific Integrated Circuits (ASIC).[334] Aerojet Rocketdyne supplies propulsion, while guidance electronics rely on niche vendors with limited surge elasticity.[335] These constraints have led to doubling production efforts in FY2023–FY2025; however, backlogs persist due to simultaneous demand from the Indo-Pacific and NATO regions.

RIM-161 Standard Missile 3

For the RIM-162 SM-3 export, licensing challenges were created in the collaborative development efforts, the Block IIA variant was co-developed with Mitsubishi Heavy Industries, which controlled the third-stage motor and nose cone.[336] Exporting to Japan and potential integration with Dutch naval systems required multinational memoranda of understanding and compliance with the Missile Technology Control Regime (MTCR).[337] Raytheon Corp. manufactures the missile in Tucson, while Aerojet Rocketdyne supplies the MK 72 booster and Throttling Divert and Attitude Control System (TDACS) propulsion.[338] The Lightweight Exo-Atmospheric Projectile (LEAP) kinetic kill vehicle remains a single-source component with no commercial analog.[339] These factors constrain surge scalability and limit tactical repurposing outside strategic Ballistic Missile Defense (BMD) roles.

AIM-7 Sparrow

The AIM-7 Sparrow, once the principal United States medium-range air-to-air missile, is now largely obsolete. What has become evident through the Russo-Ukraine war, as stockpiles become depleted, is that legacy hardware is being deployed to supplement weapon stockpiles, suggesting that surge vulnerability could exist despite no active production and severe component obsolescence. Previous exports to Italy and the United Kingdom led to the development of AIM-7, a variant of the Italian Aspide missile and the United Kingdom's Skyflash missile, which, in turn, led to divergent seeker architectures and complicated interoperability. Japan is also an AIM-7 export recipient, but Japan's transition away from the AIM-7 to the Mitsubishi AAM-4 further underscores the system's obsolescence.[340] Initially produced by Hughes and then by Raytheon, the AIM-7 Sparrow relied on the Hercules MK-58

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[331] DSCA Staff, Japan – AIM-120D-3 and AIM-120C-8 AMRAAM, *Defense Security Cooperation Agency* (Jan. 2, 2025), *available at* https://www.dsca.mil/Press-Media/Major-Arms-Sales/Article-Display/Article/4020619/japan-aim-120d-3-and-aim-120c-8-advanced-medium-range-air-to-air-missiles-amraam.

[332] *Id.*

[333] *Id.*

[334] Weapon System, *supra*, note 312.

[335] DAMIR Staff, *supra*, note, 313.

[336] GS Staff, *supra*, note 248.

[337] *Id.*

[338] Raytheon Staff, Most Advanced AMRAAM Variant, AIM-120D-3, Completes Critical Milestone for Operational Use, *Raytheon Corp.* (Apr. 8, 2023), *available at* https://www.rtx.com/news/news-center/2023/04/18/most-advanced-amraam-variant-aim-120d-3-completes-critical-milestone-for-operat.

[339] *Id.*

[340] Audrey Decker, Aerojet Digging 'Out of This Hole' as It Clears Rocket Backlog, President Says, *Defense One* (Sep. 27, 2024), *available at* https://www.defenseone.com/business/2024/09/aerojet-digging-out-hole-it-clears-rocket-backlog-president-says/399905/.

motor, which is no longer manufactured. Reactivation may require full seeker and propulsion redesign.[341] The AIM-7 Sparrow's legacy status renders it nonviable for surge reconstitution under modern combat conditions.

RIM-7 Sea Sparrow

The RIM-7 Sea Sparrow defends against sea-skimming threats. While still operational in some fleets, it faces severe surge constraints. Exports are tied to compatibility with shipboard radar illuminators and launch systems.[342] The NATO Sea Sparrow Project Office coordinates multinational sustainment; however, legacy variants face challenges in integration and sustainment.[343]

Jointly developed by Raytheon and General Dynamics, the RIM-7 Sea Sparrow uses the same MK-58 motor as the AIM-7 Sparrow. Vertical launch adaptations, such as the MK 48 Guided Missile Vertical Launching System (GMVLS), require ship-specific integration, which limits modularity.[344] With ESSM Block 2, an enhanced version of the RIM-162 Evolved Sea Sparrow Missile, now dominant, the RIM-7 Sparrow is functionally deprecated and surge-inert.[345] Because the RIM-7 Sparrow evolved from the AIM-7 Sparrow, conventional wisdom would suggest the ability to convert the RIM-7 Sparrow to the AIM-7 Sparrow or vice versa. It would be a non-trivial retrofit requiring substantial modification across propulsion, guidance, launch interface, and platform integration.[346] The Sea Sparrow program was developed in the 1960s, but the resulting RIM-7 Sea Sparrow diverged significantly from its airborne ancestor.

The AIM-7 Sparrow, a semi-active radar-homing air-to-air missile developed in the postwar period, served as the foundational architecture for the RIM-7 Sea Sparrow, a ship-launched surface-to-air missile introduced in the 1960s to counter the emerging threat of sea-skimming aircraft and anti-ship missiles. While the RIM-7 Sea Sparrow was initially derived from the AIM-7 Sparrow, the two systems have since diverged significantly in form, function, and integration requirements. As such, the feasibility of converting AIM-7 Sparrow airframes into RIM-7 Sea Sparrow naval variants today is technically possible but operationally impractical.

The original Sea Sparrow program was conceived as a rapid retrofit solution for naval vessels lacking modern missile defenses. It leveraged the AIM-7 Sparrow's radar-guided architecture but required substantial modification to accommodate shipboard launch dynamics.[347] These included the addition of folding wings, clipped fins, and hardened airframes to withstand deck handling and vertical launch stresses.[348] The missile's propulsion system was then adapted for cold launch from stationary platforms, requiring rapid motor ignition and safe clearance from the ship's superstructure.[349]

Given these issues, converting AIM-7 Sparrow airframes into RIM-7 Sea Sparrows today would likely require a comprehensive systems engineering effort, akin to developing a new missile. The obsolescence of key components, most notably the Hercules MK-58 motor, and the retirement of production tooling further compound the challenge.[350] The United States Navy and allied fleets have transitioned to the RIM-162 Evolved Sea Sparrow Missile, which incorporates active radar homing, a modular architecture, and full vertical-launch compatibility, thereby severing the Sparrow lineage.[351]

While the RIM-7 Sea Sparrow originated as a naval adaptation of the AIM-7 Sparrow, the feasibility of reverse-converting or repurposing AIM-7 Sparrows into RIM-7 Sea Sparrows in the current operational environment is doubtful. The effort would probably be cost-prohibitive, tactically regressive, and strategically unjustified given the availability of modern alternatives.

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[341] Filippo Carfagna, Elisa Castoldi, Mattia Dotti, Francesco Gigante, Tommaso Messa, & Alessandro Turano, AIM-7M Sparrow: Conceptual Design for Upgrades in Range, Velocity and Maneuverability, *Laboratorio di Propulsione Aerospaziale Dip. Scienze e Tecnologie Aerospaziali* (2018), *available at* https://turano.io/projects/Launch_Systems.pdf.

[342] Jacob Gleasun, Sea Sparrow Missile, *Missile Defense Advocacy Alliance* (Jul. 2017), *available at* https://missiledefenseadvocacy.org/missile-defense-systems-2/missile-defense-systems/u-s-deployed-intercept-systems/sea-sparrow-missile/.

[343] *Id.*

[344] Sea Forces Staff, RIM-7 Sea Sparrow Missile SAM, *Seaforces.org* (n.d.), *available at* https://www.seaforces.org/wpnsys/SURFACE/RIM-7-Sea-Sparrow.htm.

[345] *Id.*

[346] *Id.*

[347] Norman Friedman, *supra*, note 81.

[348] *Id.*

[349] *Id.*

[350] *Id.*

[351] *Id.*

Surge Capacity Issues for Selected United States Active Missiles

MIM-104 Patriot (PAC-3 MSE)

The MIM-104 Patriot system remains a cornerstone of the United States and allied air and missile defense systems.[352] [353] The MIM-104 Patriot system's surge vulnerability is moderate, constrained by system complexity and integration dependencies. Patriot exports require end-use monitoring and co-licensing with radar. Japan's 2024 transfer of Patriot missiles to the United States suggested a legal overhaul of its arms export laws.[354] The MIM-104 Patriot is the entire Patriot missile system, which includes the PAC-2, an older Patriot missile, and the PAC-3, a newer Patriot missile.[355] The PAC-3 Missile Segment Enhancement (MSE) is a missile that destroys targets by colliding with them, unlike the PAC-2 models that used a blast-fragmentation warhead.[356] The PAC-3 model also features a distinct internal configuration, including an active KA-band radar seeker and attitude control motors for precision maneuvering, and can accommodate four missiles per canister, compared to one PAC-2 missile.[357]

Lockheed Martin Corp. produces the PAC-3 MSE missile, Raytheon supplies radar systems, and Boeing manufactures the missile launchers.[358] Integration occurs at Redstone Arsenal. Dual-pulse motors and hit-to-kill guidance are single-source components with long lead times.[359] Despite expanded production, surge capacity remains constrained by the availability of radar and launchers, as well as system-level integration.

THE SURGE CAPACITY PROBLEM

In this section, the surge capacity problem is presented in the first subsection, where the current Russian-Ukrainian and Israeli-Iranian conflicts indicate that the United States lacks the surge capacity to meet the needs of its allies in times of war. The second subsection provides examples from World War II, during which the United States had an ample surge capacity to produce weapons of war efficiently and effectively.

Surge Capacity Problem Statement

This article examines the critical imbalance between missile attrition rates and replenishment capacity within the United States and allied defense resupply system under conditions of sustained, high-intensity warfare against peer adversaries. The issue is whether the United States possesses sufficient surge capacity to produce specific missiles in the time of war or during a military conflict in which it or one or more allies is engaged, where the United States supplies these allies with active missiles.

For example, in Ukraine, Russian forces launched over 5,000 long-range munitions in July 2025 alone, including 728 drones in a single day, while Ukraine's air defenses intercepted hundreds every night.[360] [361] [362] Despite Western resupply efforts, Ukrainian forces continued to face persistent shortages of interceptors, cruise missiles, and guided munitions, underscoring the fragility of surge logistics and the time lag between battlefield consumption and industrial replenishment. Based on this information, it is reasonable to infer that the United States likely lacks sufficient surge capacity, while Russia probably has substantial surge capacity.

Furthermore, during the recent war between Israel and Iran, Iran fired 550 ballistic missiles and 1,000 drones, with 31 impacts in populated areas, resulting in 28 Israeli fatalities and over 3,000 injuries.[363] Israel's retaliatory campaign destroyed over 1,000 Iranian missiles and 250 launchers, yet the operation consumed thousands of precision-guided munitions and required over

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352 U.S. Army Staff, PATRIOT: The U.S. Army's Most Advanced Air Defense System, Redstone Arsenal Historical Information (n.d.), *available at* https://history.redstone.army.mil/miss-patriot.html

353 CI Geography Straff, Patriot: The Cornerstone of Western Air and Missile Defense, *CI Geography* (Nov. 27, 2023), *available at* https://www.cigeography.com/articles/patriot-the-cornerstone-of-western-air-and-missile-defense.

354 Editorial Team, Comprehensive Guide to MIM-104 Export Policies, *Military Sphere* (May 29, 2024), *available at* https://militarysphere.com/mim-104-export-policies/.

355 *See generally*, Norsk Luftern Staff, The Patriot Missile System's Transformation from Cold War Concept to Modern Hypersonic Interceptor – Costs and Capabilities, *Norsk Luftern* (Aug. 6, 2025), *available at* https://norskluftvern.com/2025/08/06/the-patriot-missile-systems-transformation-from-cold-war-concept-to-modern-hypersonic-interceptor-costs-and-capabilities/#:~:text=PAC-3%20development%20(2001-,impact%20rather%20than%20proximity%20explosion.

356 *Id.*

357 *Id.*

358 Defence Database Staff, *supra*, note 243.

359 *Id.*

360 Kevin Shalvey, 2 Dead as Russia Attacks Ukraine Overnight with Almost 600 Drones, Kyiv Says, *ABC News* (Jul. 12, 2025), *available at* https://abcnews.go.com/International/russian-strike-on-ukraine-overnight-600-drones/story?id=123697825.%20[Accessed%2027%2012%202025].

361 UN Staff, UN Warns of Escalating Human Toll in Ukraine Amid Relentless Aerial Attacks, Mounting Aid Shortfall, *UN News* (Jul. 25, 2025), *available at* https://news.un.org/en/story/2025/07/1165499.

362 RFE/RL Staff, Nearly 400 Drones, Missiles Fired At Ukraine As Russia Shows No Signs Of Let-Up, *Radio Free Europe/Radio Liberty* (Jul. 19, 2025), *available at* https://www.rferl.org/a/ukraine-russia-drones-missiles-putin-trump-war/33478432.html.

363 *Id.*

600 aerial refueling sorties.[364] The conflict exposed the vulnerability of even advanced missile defense systems under saturation conditions and highlighted the strategic cost of maintaining deterrence at scale.[365] This example suggests that Iran also has substantial surge capacity.

These two examples reveal that attrition rates in modern missile warfare can exceed replenishment timelines by orders of magnitude. Contributing factors include legacy production constraints, component obsolescence, workforce reactivation delays, and mineral dependencies concentrated in geopolitically sensitive regions.[366] This indicates the need for investment in surge capacity, suggesting that the United States could enter future conflicts with inadequate missile inventories and degraded strategic credibility.

Historical Considerations

The story began on December 7, 1941, when Japan bombed Pearl Harbor.[367] The attack was a response to the sanctions imposed by the United States on Japan.[368] Although there is some dispute as to whether the United States deciphered a Japanese coded message indicating that the country was about to bomb Pearl Harbor, 2,403 sailors, soldiers, and civilians were either killed or wounded on that fateful day.[369] On December 8, 1941, President Franklin D. Roosevelt spoke before a joint session of Congress, asking for a declaration of war. His request was granted.[370] On December 11, 1941, Congress declared war on Germany, and on that same day, Germany returned the favor.[371]

On September 11, 1941, President Roosevelt publicly declared that he had ordered the American Navy and Air Force to shoot any German war vessel on sight.[372] In his speech of October 27, 1941, President Roosevelt vigorously affirmed that this order was in force. Under this order, vessels of the American Navy, since early September 1941, had been systematically attacking German naval forces.[373] For example, the American ships the Greer, the Kearney, and the Reuben James fired on German submarines, as confirmed by Mr. Frank Knox, the Secretary of the American Navy.[374] Thus, the declaration of war against Germany by the United States was merely an official recognition of a previous, unofficial kinetic conflict.

With the United States' entrance into World War II, the country possessed an advantage because two oceans separated it from the hostilities in Europe and Asia. Even before entering World War II, in November 1941, the United States supplied the Union of Soviet Socialist Republics (USSR) with $1 billion in interest-free credit in the form of Lend-Lease materiel and raw materials.[375] In terms of 2025 dollars, this figure translates to $21.9 billion.[376] Before the United States entered the war, the country's manufacturing base was gearing up for the war.

The volume of war weapons was staggering. Companies that were already involved in defense work expanded. The automobile industry was entirely transformed. Instead of making automobiles, Chrysler made fuselages, General Motors made

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[364] Alia Chughtai, Visualising 12 Days of the Israel-Iran Conflict, *Al Jazeera* (Jun. 26, 2025), *available at* https://www.aljazeera.com/news/2025/6/26/visualising-12-days-of-the-israel-iran-conflict.
[365] *Id.*
[366] Tamara Qiblawi, Gianluca Mezzofiore, & Madalena Araujo, US Used About a Quarter of its High-End Missile Interceptors in Israel-Iran War, Exposing Supply Gap, *The Jewish Institute for National Security of America* (Jul. 29, 2025), *available at* https://jinsa.org/us-used-about-a-quarter-of-its-high-end-missile-interceptors-in-israel-iran-war-exposing-supply-gap/.
[367] The Editors of the Encyclopedia Britannica, Pearl Harbor Attack, *Encyclopedia Britannica* (Aug. 26, 2025), *available at* https://www.britannica.com/event/Pearl-Harbor-attack.
[368] Sarah Pruitt, Why Did Japan Attack Pearl Harbor?, *History.com* (Jan. 31, 2025), *available at* https://www.history.com/articles/why-did-japan-attack-pearl-harbor.
[369] Clare Mulroy, How Many People Died in Pearl Harbor? Here Are the Casualties of the 1941 Attack,. *USA Today* (Jan. 24, 2024), *available at* https://www.usatoday.com/story/news/2023/05/12/how-many-people-died-in-pearl-harbor/70205711007/.
[370] LOC Staff, Speech by Franklin D. Roosevelt, New York (Transcript), *The Library of Congress* (Dec. 8, 1941), *available at* https://www.loc.gov/resource/afc1986022.afc1986022_ms2201/?st=text.
[371] U.S. Senate, Declaration of War with Germany, WWII (S.J.Res. 119), *United States Senate* (Dec. 11, 1941), *available at* https://www.senate.gov/about/images/documents/sjres119-wwii-germany.htm#:~:text=The%20declaration%20of%20war%20with,the%20resolution%2C%2088-0.
[372] Joachim von Ribbentrop, German Declaration of War with the United States : December 11, 1941, *Yale Law School: Lillian Goldman Law Library* (Dec. 11, 1941), *available at* https://avalon.law.yale.edu/wwii/gerdec41.asp#:~:text=The%20Avalon%20Project%20%3A%20The%20German,United%20States%20%3A%20December%2011%2C%201941&text=(Including%20the%20circumstances%20of%20the,Charge%20d'Affaires%2C%20Dr.
[373] *Id.*
[374] *Id.*
[375] Lauren Monsen, & Sait Serkan Gurbuz, America Sent Gear to the USSR to Help Win World War II, *Share America* (May 3, 2023), *available at* https://archive-share.america.gov/america-sent-equipment-to-soviet-union-in-world-war-ii/index.html#:~:text=Americans%20also%20sent%20guns%2C%20ammunition,and%20services%20to%20the%20Soviets.
[376] Ian Webster, $1,000,000 in 1941 Is Worth $21,868,367.35 Today, *CPI Inflation Calculator* (n.d.), *available at* https://www.in2013dollars.com/us/inflation/1941?amount=1000000.

airplane engines, guns, trucks, and tanks, Packard made Rolls-Royce engines for the British air force, and the Ford Motor Company performed a manufacturing miracle 24 hours a day.[377] At the time, the average Ford car had some 15,000 parts. A B-24 Liberator long-range bomber had 1,550,000 parts, and one was assembled entirely every 63 minutes.[378]

Shipyards manufactured vessels so fast that by the autumn of 1943, all Allied shipping sunk since 1939 was replaced.[379] In 1944 alone, the United States manufactured more planes than the Japanese did from 1939 to 1945. At the end of World War II, over 50 percent of the world's industrial production occurred in the United States. Not only did wartime production boom, but American citizens also clustered to meet labor demand. The labor union pledged not to strike during the war. When the United Mine Workers went on strike in 1943, newspapers condemned the union as traitors. This is a striking contrast to what happened in Germany in 1916 and 1918 when workers went on strike during World War I.[380] As 16 million Americans went to war, 24 million Americans, including 8 million women, found job opportunities that did not exist before 1941.[381]

The economy of Mobile, Alabama, underwent a significant transformation.[382] In 1940, local shipyards won contracts to build Liberty ships and destroyers. During World War II, Alcoa Aluminum Corp. processed 1 million pounds of alumina, which was used to construct 304,000 airplanes.[383] In 1940, Gulf Shipbuilding had 240 employees; by 1943, it had employed 11,600 workers. The Alabama Dry Dock grew from 1,000 workers to nearly 30,000 employees. The Mattatuck Manufacturing Company began producing cartridge clips for the Springfield rifle instead of upholstery nails, churning out 3 million clips a week.[384] The American Brass Company manufactured more than 2 billion pounds of brass rods, sheets, and tubes. The Chase Brass and Copper Company created more than 50 million cartridge cases and mortar shells, and more than a billion small-caliber bullets.[385] Most factories produced war goods 24 hours a day, 7 days a week, including Saturdays and Sundays.[386]

The Current Situation

The data indicate that during World War II, the United States had ample surge capacity. But what about today? Tables 1, 4, 7, and 10 indicate that active missile production in the United States is accomplished at only three companies. Essentially, during World War II, military manufacturing was a highly competitive market, with likely hundreds of companies contributing to the war effort. Over the 80 years following the end of World War II in 1945, the active missile production industry in the United States has evolved into an oligopoly, characterized by low production volumes for some missiles but high costs. Given that the United States may be facing conflicts in multiple theaters in the near future, this situation needs to change, and change quickly if possible.

Economics of the Surge Capacity Problem

Suppose for a given active missile, the surge capacity problem did not exist. From an economic perspective, the supply of missiles would intersect the demand for missiles. But more importantly, the supply curve would not have a kink, where the slope of the supply curve abruptly changed, and became vertical. In other words, the primary missile manufacturer would have no issue in supplying the needs of the DOD. The primary missile manufacturer would make more missiles until the demand curve was crossed at an equilibrium or market-clearing point, where the quantity of missiles produced is at the agreed-upon price. Graphically, this situation appears as shown in Figure 1.

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[377] WTTW Staff, War Production, *Public Broadcasting Service: WTTW* (2007), *available at* https://www.pbs.org/kenburns/the-war/war-production#:~:text=American%20industry%20provided%20almost%20two,world's%20largest%2C%20doubled%20in%20size.
[378] *Id.*
[379] *Id.*
[380] Klaus Weinhauer, Labour Movements and Strikes, Social Conflict and Control, Protest and Repression (Germany), *International Encyclopedia of the First World War* (Oct. 10, 2017), *available at* https://encyclopedia.1914-1918-online.net/article/labour-movements-and-strikes-social-conflict-and-control-protest-and-repression-germany/.
[381] WTTW Staff, *supra*, note 377.
[382] *Id.*
[383] *Id.*
[384] *Id.*
[385] *Id.*
[386] *Id.*

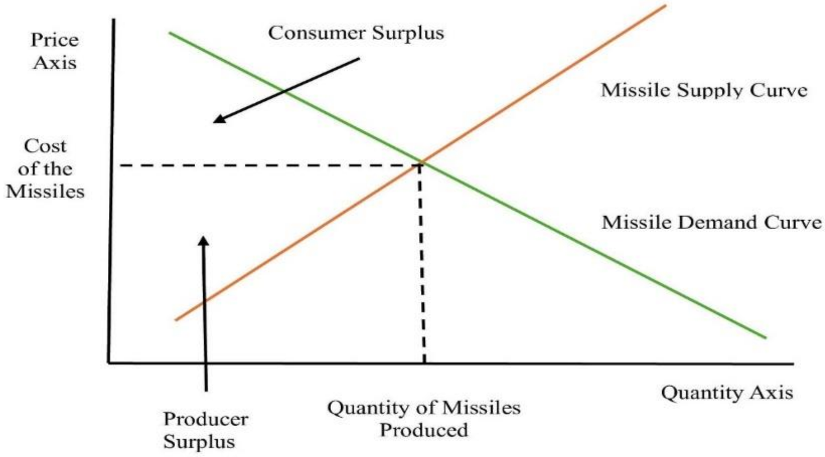

Figure 1. Missile Supply and Demand Curves without a Surge Capacity Problem

This is a standard supply-and-demand graph that one would see in any economics textbook.[387] The areas of the consumer and producer surpluses depend strictly on the shapes or slopes of the supply and demand curves. Notice that in this instance, there are no kinks in the supply curve. Now, if there is a surge capacity problem and the primary missile manufacturer's production capacity occurs before the equilibrium quantity, then the missile supply curve would have a kink at the quantity at which the missile is produced. Figure 2 depicts supply and demand, and assumes that the kink appears before the supply curve intersects the demand curve. At the quantity where the maximum production occurs, the supply curve becomes vertical.

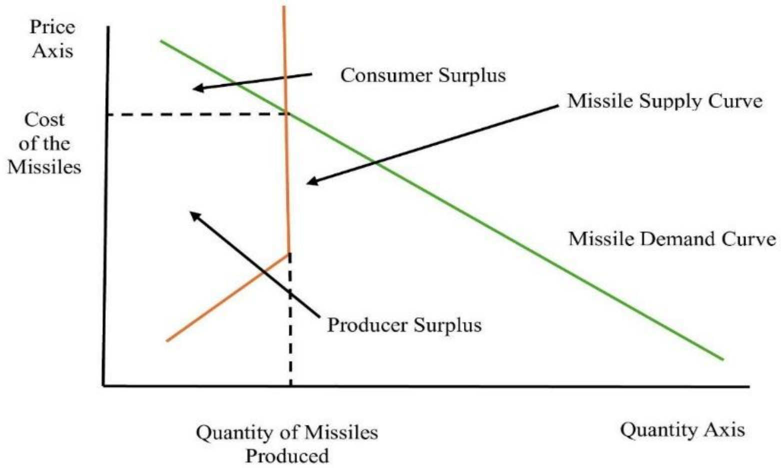

Figure 2. Missile Supply and Demand Curves with a Surge Capacity Problem

Notice that in Figure 2, the producer surplus is much larger than the consumer surplus. Given that the supply curve is vertical, and thus infinitely inelastic, the primary missile manufacturer has an economic incentive to keep the maximum production such that the supply curve never intersects the missile demand curve at the point where there is no surge capacity problem. The issue with inelastic supply curves is that when the percentage change in quantity decreases, the percentage change in price increases by more than the percentage decline in quantity. The result is that for inelastic supply curves, revenue increases when the percentage change in quantity decreases. This fact serves as an incentive for a primary missile manufacturer to maintain relatively low production of a given missile, thereby increasing its revenue. Presumably, as revenue increases, so do profits, assuming that the costs of production remain approximately the same as quantity declines.

POTENTIAL CAUSES OF THE SURGE CAPACITY PROBLEM

In this section, nine possible causes of the surge capacity problem in producing active missiles are discussed, including:

- Market concentration issues;
- City and State laws and regulations that could limit manufacturing expansion;
- Federal laws and international treaties that may limit manufacturing expansion;
- Physical limitations of manufacturing facilities;
- Issues with building new manufacturing facilities;

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[387] PAUL KRUGMAN, & ROBIN WELLS, ECONOMICS (Worth Publishers 6th ed. Jan. 2021).

- Innovation development issues;
- Missile complexity issues;
- Engineering design issues;
- Department of Defense requirements issues;
- Just-in-time manufacturing issues;
- Lean manufacturing issues; and
- Labor issues.

Market Concentration Issues

From Tables 1, 4, 7, and 10, it is evident that the missile manufacturing industry is at least an oligopoly, if not a monopoly. When taking the joint venture for the FGM-148 Javelin into consideration, and ascribing 50 percent equally of primary manufacturing to both Raytheon Corp. and Lockheed Martin Corp., of the 22 active missiles discussed herein. Of these 22 missiles, 16.5 missiles are built by Raytheon Corp., Lockheed Martin Corp. produces 2.5 missiles, The Boeing Company manufactures two missiles, and Kongsberg Defence and Aerospace AS makes one missile. In percentage terms, Raytheon Corp. enjoys a 75.01 percent market share, Lockheed Martin Corp. has an 11.36 percent market share, The Boeing Company possesses a 9.09 percent market share, and Kongsberg Defence and Aerospace AS experiences a 4.54 percent market share. Table 13 depicts these market share concentration percentages in tabular form.

Table 17. Active Missile Manufacturing Industry Market Concentration Percentages

Company	Market Share Percentage
Raytheon Corp.	75.01 percent
Lockheed Martin Corp.	11.36 percent
The Boeing Company	9.09 percent
Kongsberg Defence & Aerospace AS	4.54 percent
Total	100.00 percent

The question that naturally arises from the large market share percentages held by Raytheon Corp. is whether the company is a monopoly. The Herfindahl-Hirschman Index (HHI) is a measure of market concentration that is often used in conjunction with concentration ratios.[388] Usually, the HHI is calculated using the top four firms in an industry.[389] In this instance, there are precisely four companies in the market. The HHI is calculated by summing the squares of the market share percentages. The higher the sum, the greater the industry concentration. The maximum HHI value is 10,000 (= 100.0^2).[390] In this instance, the HHI equals 5,858.79 (= $75.01^2 + 11.36^2 + 9.09^2 + 4.54^2$).

According to the Antitrust Division of the United States Department of Justice (DOJ), an HHI value between 1,000 and 1,800 is a moderately concentrated industry, while an HHI value of more than 1,800 is a highly concentrated industry.[391] Here, the HHI exceeds 2.5 times 1,800, indicating that the active missile manufacturing industry is likely a monopoly. Although monopolies are not necessarily illegal, they typically charge higher prices and produce a lower quantity than their perfectly competitive counterparts.[392] Thus, Raytheon Corp.'s high concentration ratio may act as a disincentive to increase capacity, as management may believe the company's current manufacturing capacity is sufficient to meet the federal government's active missile needs.

[388] Michael Bromberg, Herfindahl-Hirschman Index (HHI): Definition, Formula, and Example, Investopedia (Jun. 10, 2025), *available at* https://www.investopedia.com/terms/h/hhi.asp.
[389] *Id.*
[390] *Id.*
[391] DOD Staff, Herfindahl-Hirschman Index, *U. S. Department of Justice* (Jan. 17, 2024), *available at* https://www.justice.gov/atr/herfindahl-hirschman-index#:~:text=The%20HHI%20takes%20into%20account,controlled%20by%20a%20single%20firm.
[392] Paul Krugman, & Robin Wells, *supra*, note 387.

City and State Laws and Regulations that Could Limit Manufacturing Expansion

City and state laws and regulations can limit the expansion of manufacturing for producing active missiles. Some issues with city ordinances could include:[393 394]

- ***Zoning Ordinances:*** Local zoning ordinances that deal with manufacturing districts could impact missile production expansion. These ordinances may dictate allowed uses, building height, setbacks, and other requirements for industrial properties. Any building expansion would likely need to comply with the zoning district regulations for the specific site.
- ***Unified Development Ordinance (UDO):*** A local city or town may have a UDO ordinance that merges and updates development regulations. This document typically governs land use and development within a local community. It would necessarily need to be consulted before any manufacturing expansion plans are implemented.
- ***Environmental Regulations:*** A local community may have ordinances that address environmental concerns, such as noise, vibration, and solid waste disposal. Any manufacturing expansion, including missile production, would likely have to comply with these regulations to prevent nuisances and environmental damage.
- ***Permitting Requirements:*** Expanding manufacturing operations would likely require various permits and approvals from a town's or city's Planning and Zoning Department, including possibly a conditional use permit, provided the specific use is not explicitly allowed by-right within the zoning district.

State laws and regulations that could also prevent an active United States missile producer from expanding its manufacturing facilities include:[395]

- ***Environmental Protection Laws:*** The state may have comprehensive environmental protection laws that govern air pollution, water pollution, hazardous waste materials, and hazardous waste management.
- ***Building Codes and Regulations:*** A state likely possesses building codes, fire codes, and safety regulations that would affect any new construction or expansion of manufacturing facilities.
- ***Worker Safety and Health:*** A state would likely uphold worker safety and health regulations, which are essential in a high-risk industry like missile manufacturing. The state occupational safety and health department could also be involved in administering workplace safety practices.

Federal Laws and International Treaties that May Limit Manufacturing Expansion

Some of the federal laws that could limit further active missile production are:

- ***Defense Production Act (DPA) of 1950:*** The DPA allows the United States government to prioritize and allocate resources for national defense, including expanding manufacturing capacity for critical items like missile components. This indicates that the federal government plays a significant role in influencing missile production.[396]
- ***Arms Export Control Act (AECA) of 1976:*** Missile technology is subject to export controls under the AECA, as well as related regulations preventing the proliferation of missiles and missile technology. While the AECA mainly deals with international transfers, it highlights the delicate issues related to missile-related activities.[397]

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[393] *See generally*, Kendra Blacksher, Manufacturers Navigate Tighter Environmental Regulation, *RSM* (Jan. 10, 2024), *available at* https://rsmus.com/insights/industries/manufacturing/manufacturers-navigate-tighter-environmental-regulation.html#:~:text=Investment%20in%20domestic%20manufacturing%20expansion,to%20make%20the%20process%20tougher.

[394] *See generally*, RHP Staff, Industrial / Manufacturing Facility Safety, *Risk Management: Consulting Health Scientists* (n.d.), *available at* https://rhprisk.com/industrial-manufacturing-facility-safety/.

[395] *See generally*, IDNR Staff, Explosives, Handling & Storage: The Illinois Explosives Act, *Illinois Department of Natural Resources* (n.d.), *available at* https://dnr.illinois.gov/mines/ead/explosiveshandlingstorage.html#:~:text=The%20Illinois%20Explosives%20Act,storage%20facilities%20and/or%20users.

[396] CRS Staff, The Defense Production Act of 1950: History, Authorities, and Considerations for Congress, *Congressional Research Service* (n.d.), *available at* https://www.congress.gov/crs-product/R43767#:~:text=The%20Defense%20Production%20Act%20of%201950%2C%20as%20amended%20(DPA),30%2C%202025%2C%20unless%20reauthorized.

[397] LII Staff, Arms Export Control Act (1976), *Legal Information Institute* (n.d.), *available at* https://www.law.cornell.edu/wex/arms_export_control_act_(1976)#:~:text=The%20Arms%20Export%20Control%20Act,these%20items%20is%20not%20permitted.

Surge Capacity Issues for Selected United States Active Missiles

International treaties that may limit the expansion of active missile production include:

- ***Strategic Arms Limitation Talks (SALT I and SALT II) of 1972 and 1979, Respectively:*** These treaties between the United States and the USSR focused on curbing the nuclear arms race. The first treaty, SALT I, limited anti-ballistic missile (ABM) systems, putting restrictions on ICBMs and submarine-launched ballistic missiles (SLBMs). The second treaty, SALT, set limits on strategic launchers, including those equipped with multiple independently targetable reentry vehicles (MIRVs). The United States Senate never ratified SALT II.[398]
- ***Intermediate-Range Nuclear Forces Treaty (INFT) of 1987:*** This treaty between the United States and the USSR barred ground-launched ballistic and cruise missiles with ranges between 500 and 5,500 km. In 2019, the United States withdrew from the treaty.[399]
- ***Missile Technology Control Regime (MTCR) of 1987:*** This informal arrangement among 35 countries seeking to limit the spread of unmanned delivery systems for weapons of mass destruction (WMD). It created guidelines and controls for the export of missiles and missile-related equipment and technology, particularly those capable of delivering a 500 kg payload at least 300 km.[400]
- ***Strategic Arms Reduction Treaties (START) of 1991 and 2010:*** These treaties aimed to significantly reduce strategic nuclear weapons, including missiles and warheads, and strategic offensive arms.[401] [402]
- ***United Nations Security Council Resolution 1540 of 2004:*** This resolution requires all United Nations (UN) member states to preclude non-state actors from acquiring nuclear, chemical, or biological weapons and their delivery systems.[403]

Any manufacturing expansion, particularly in a sensitive area like missile production, would be subject to a complex interplay of city ordinances, state laws, federal laws and regulations, as well as international treaties, especially those related to zoning, environmental protection, and safety. An active missile manufacturing company should consult with the relevant authorities to ensure full compliance with all applicable laws and regulations.

Physical Limitations of Existing Manufacturing Facilities

In the short run, every manufacturing facility, regardless of what is being produced, is limited by the square footage of its existing facilities. Suppose an active missile producer possesses an existing manufacturing plant that is not utilizing all of its square footage. In that case, the company can expand its production by utilizing that square footage to its manufacturing advantage. Suppose a firm owns a plant that it previously decided not to use. In that case, the entity can bring that plant online by installing productive devices and making some of the space available to its employees, either as office space or assembly space. In either case, the organization will likely need to obtain the needed city and state permits and licenses, as described above, to utilize the empty facility. This effort may take some time, but if the need is great, these governmental bodies may be inclined to expedite the permit and license process. As for the federal government, if there is a presidential or congressional mandate to significantly increase active missile production, it is more likely that bureaucratic red tape will be expeditiously cut, and the surge capacity problem will be resolved.

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[398] Daryl G. Kimball, U.S.-Russian Nuclear Arms Control Agreements at a Glance, *Arms Control Association* (Oct. 2022), *available at* https://www.armscontrol.org/factsheets/us-russian-nuclear-arms-control-agreements-glance.

[399] Daryl G. Kimball, The Intermediate-Range Nuclear Forces (INF) Treaty at a Glance, *Arms Control Association* (Aug. 2019), *available at* https://www.armscontrol.org/factsheets/intermediate-range-nuclear-forces-inf-treaty-glance#:~:text=On%20Aug.,please%20contact%20us%20for%20assistance.

[400] Kelsey Davenport, The Missile Technology Control Regime at a Glance, *Arms Control Association* (Mar. 2021), *available at* https://www.armscontrol.org/factsheets/missile-technology-control-regime-glance#:~:text=A%20Russian%20Topol-M%20intercontinental,chances%20of%20joining%20the%20MTCR.

[401] CACNP Staff, Strategic Arms Reduction Treaty (START I), *Center for Arms Control and Non-Proliferation* (Nov. 16, 2022), *available at* https://armscontrolcenter.org/strategic-arms-reduction-treaty-start-i/.

[402] Xiaodon Liang, New START at a Glance, *Arms Control Association* (Dec. 2024), *available at* https://www.armscontrol.org/factsheets/new-start-glance#:~:text=Duration%20and%20Withdrawal%20(Article%20XIV,from%20a%20notice%20of%20withdrawal.

[403] ODA Staff, UN Security Council Resolution 1540 (2004), *United Nations Office of Disarmament Affairs* (2004), *available at* https://disarmament.unoda.org/wmd/sc1540/.

Innovation Development Issues
According to TrafficTide Solutions, the missiles market size was valued at $95.3 billion in 2024.[404] It is forecasted to grow at a compound annual growth rate (CAGR) of 4.1 percent from 2026 to 2033, reaching $135.6 billion by 2033.[405] The following factors drive the growth of the missiles market:[406]

- Increased demand for defense and security by various nations;
- Technological advancements in missile guidance systems, propulsion, and warhead capabilities are due to precision targeting with the integration of artificial intelligence (AI);
- Expansion of military spending by emerging countries;
- Modernization of defense forces in developed nations;
- Growing threat of asymmetric warfare, regional conflicts, and geopolitical tensions; and
- Rise in missile defense systems focused on neutralizing threats.

TrafficTide Solutions aptly observed that technological innovations are a significant barrier to missile market growth.[407] The challenge lies in developing advanced missile systems with state-of-the-art technology while ensuring cost-effectiveness, operational effectiveness, and efficiency.[408] The research and development costs for creating advanced electric propulsion systems, GPS guidance, and multi-purpose warheads are expensive. This statement also holds for anti-missile systems.[409] [410]

With advanced propulsion and guidance systems come increased costs. The costs could be mitigated if the propulsion and guidance systems become increasingly simpler without losing any valuable functionality. This can be achieved by realizing economies of scale when developing propulsion and guidance systems. Simplicity is never simple to achieve. However, once accomplished, the cost of propulsion and guidance systems can potentially decrease significantly, provided that the components used are not necessarily employed for the sake of technological superiority. Some low-tech solutions are pretty effective and efficient to implement. It depends on the developers' willingness to create low-cost solutions without sacrificing technological effectiveness.

Missile Complexity Issues
As technology advances, the complexity of the United States' active missiles also increases. The reason is that the military wants its missiles to do more than merely seek a target based on its heat signature or its geolocation. The DOD is actively embracing advanced technologies to enhance accuracy, adaptability, and discrimination capabilities against increasingly cutting-edge threats.[411] The enhanced sensors and guidance technologies include:[412]

- ***Multi-mode guidance:*** Modern missiles combine various guidance methods, including Inertial Navigation Systems (INS), GPS-based guidance, active/passive radar, and infrared sensors.
- ***Imaging infrared (IIR) and thermal imaging:*** These systems provide significant flexibility in selecting targets when compared to traditional IR homing because IIR captures and processes detailed images, thereby permitting target discrimination in capturing and processing detailed images, allowing for better discrimination in dense environments or against countermeasures.
- ***Radar and infrared integration:*** When combining radar and IR sensors, a more accurate picture of a target emerges, particularly when drones and cruise missiles are the target.
- ***Radar and multi-spectral/hyperspectral sensing:*** Technologies like Range Resolved Doppler Radar (RRDR), when merged with IR and visible sensors, permit enhanced target identification and discrimination by revealing the target and measuring its range, velocity, and angular rates.

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404 TrafficTide Solutions, Missiles Market |Challenges, Analysis, Trends and Driving Factor, *LinkedIn.com* (Apr. 24, 2025), *available at* https://www.linkedin.com/pulse/missiles-market-challenges-analysis-trends-driving-ah4oc/.
405 *Id.*
406 *Id.*
407 *Id.*
408 *Id.*
409 *Id.*
410 GVR Staff, Missile Market Size, Share & Trends Analysis Report By Component, By Launch Mode, By Range (Short Range, Medium Range, Long Range), By End-use (Air, Navy, Ground), By Region, And Segment Forecasts, 2024 – 2030, *Grand View Research* (n.d.), *available at* https://www.grandviewresearch.com/industry-analysis/missile-market-report#:~:text=The%20prioritization%20of%20national%20defense,is%20reshaping%20the%20market%20landscape.
411 BQP Staff, Missile Guidance Challenges: Technical Barriers & Modern AI Solutions, *BQP* (Aug. 11, 2025), *available at* https://www.bqpsim.com/blogs/missile-guidance-challenges#:~:text=The%20integration%20of%20AI%20and,training%20rather%20than%20explicit%20programming.
412 *Id.*

All of these relatively new technologies seem to enthrall missile engineers who are eager to implement the latest technology to increase missile performance. However, it should be remembered that not all that glitters is gold. The implementation of new technologies comes with a price tag. First and probably foremost, just because a technology is new does not necessarily mean that it is superior to older technologies. Before a new technology is applied to missile production, it should be well understood. In other words, not only should the intended consequences be critically evaluated, but also the unintended ramifications should be appreciated. In altogether too many instances, only the advantages of employing a new technology are known. The disadvantages should be thoroughly examined to ensure that no unintended effects manifest themselves. Keeping things simple is a challenging task. Missile designs should be evaluated so that a missile is manufactured at a minimum cost while maximizing its functionality, efficiency, and effectiveness.[413]

Engineering Design Issues

It seems to be almost a byword that engineers are often eager to embrace new technology without considering the unintended consequences of their decisions.[414] Engineering is the essence of technological advancement that influences and impacts people's lives, economies, and the environment.[415] However, with great power comes great responsibility.[416] Missile design is no exception to this rule. This is a significant issue because:

- ***Missiles are complex systems:*** Missiles involve technologies with numerous interconnected components and interdependencies. Understanding these interactions and anticipating all possible outcomes can be difficult, even for experienced missile engineers.[417]
- ***Military impact of technical challenges:*** By training, engineers frequently prioritize technical feasibility and the functionality of a solution. This action can lead to overlooking or even ignoring the various implications of adopting a new technology.[418]
- ***Pressure to innovate and deliver:*** In missile development, engineers may experience pressure to deploy new technologies to gain a competitive advantage over enemy efforts. The response may be to move fast and break things, driving innovation while failing to conduct thorough risk assessments and consequence analysis.[419]
- ***Limited foresight and prediction:*** Anticipating every possible consequence of a new missile technology is a daunting task, even under ideal circumstances. For example, predicting the dramatic increase in paper consumption after the introduction of personal computers was unexpected. Long-term impacts are difficult to foresee.[420]
- ***Potential for unintended adverse effects:*** Negative outcomes can occur when misinformation is propagated, information access is limited, security issues happen, economic disruption transpires, environments change, or risks are not mitigated.[421]

A holistic and ethical approach to missile design and development are needed to mitigate these risks. Engineers could:

- Incorporate ethical considerations throughout the missile design and development process;
- Implement robust risk assessment procedures to identify and evaluate possible design threats and opportunities;
- When possible, collaborate with experts in other fields to gain a broader perspective;
- Promote a culture of ongoing learning, critically evaluating the impact of a missile technology after deployment; and
- Design missiles that are transparent and explainable, thereby encouraging better oversight and accountability.

In missile design, critical thinking, ethical reflection, and proactive risk assessment are essential to ensure that missiles under development perform their proper functions while mitigating adverse possibilities.

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[413] *See generally*, Kris Gale, The One Cost Engineers and Product Managers Don't Consider, *One Review* (n.d.), *available at* https://review.firstround.com/the-one-cost-engineers-and-product-managers-dont-consider/#:~:text=Embrace%20simplicity%20in%20your%20engineering,Celebrate%20simple%2C%20effective%20communication.
[414] Diana Kangwa, Engineering Ethics: Balancing Innovation with Responsibility, *LinkedIn.com* (Feb. 25, 2025), *available a*t https://www.linkedin.com/pulse/engineering-ethics-balancing-innovation-eng-dr-diana-kangwa-4ipof/.
[415] *Id.*
[416] *Id.*
[417] *See generally*, Tim Healy, The Unanticipated Consequences of Technology, *Santa Clara Markkula Center for Applied Ethics* (Apr. 6, 2005), *available at* https://www.scu.edu/ethics/focus-areas/technology-ethics/resources/the-unanticipated-consequences-of-technology/#:~:text=It%20is%20true%20in%20all,of%20a%20highly%20complex%20system.
[418] Nitin Nohria, & Hemant Taneja, Managing the Unintended Consequences of Your Innovations, *Harvard Business Review* (Jan. 19, 2021), *available at* https://hbr.org/2021/01/managing-the-unintended-consequences-of-your-innovations.
[419] Rachel Botsman, Tech Leaders Can Do More to Avoid Unintended Consequences, *Wired* (May 24, 2022), *available at* https://www.wired.com/story/technology-unintended-consequences/.
[420] Tim Healy, *supra*, note 417.
[421] Nitin Nohria, & Hemant Taneja, *supra*, note 418.

Surge Capacity Issues for Selected United States Active Missiles

Department of Defense Requirements Issues

The DOD requirements issues consist of the slow and expensive defense acquisition system, safeguarding high-quality and reproducible information used when making decisions, ensuring departmental readiness, modernizing the Joint Capabilities Integration and Development System (JCIDS), and implementing policies that prevent conflicts of interest.[422] [423] Recent DOD efforts aim to accelerate acquisition speed, establish information quality standards, address medical waivers, streamline the JCIDS process, and implement strict rules when contracting with certain foreign organizations.[424]

Just-in-Time Manufacturing Issues

According to Banton, just-in-time (JIT) manufacturing is a "management strategy that aligns raw-material orders from suppliers directly with production schedules."[425] The goal of this inventory strategy is to increase efficiency and decrease waste by receiving resources and materials when a production process needs them, thereby reducing inventory costs.[426] JIT manufacturing is also known as the Toyota Production System (TPS), as Toyota implemented this manufacturing system in the 1970s.[427] The advantages of JIT include short production runs and reduced costs by minimizing warehouse needs.[428] The disadvantages of JIT include potential disruptions in the supply chain. A supply chain can be disrupted by the inability to deliver inputs on time.[429] Another supply chain disruption occurs when a supply chain is overwhelmed with a massive increase in the demand for inputs.[430] The reasons are:[431]

- ***Lean Inventory:*** With JIT, there is little to no buffer stock to absorb sudden spikes in demand.
- ***Dependence on Accurate Forecasting:*** JIT depends on accurate and stable demand forecasting. With a sudden increase in demand, a JIT supply chain may struggle to acquire the needed inputs promptly.
- ***Supplier Reliance:*** JIT hinges on responsive and dependable suppliers who can deliver the pre-determined quantity of materials precisely when needed. A massive increase in demand can strain a supplier's capacity, resulting in delays and shortages.
- ***Supply-Side Vulnerabilities:*** External events, such as natural disasters, transportation disruptions, or geopolitical conflicts, can negatively impact a supplier's ability to provide raw materials when needed.
- ***Reduced Flexibility:*** An emphasis on efficiency and cost reduction can sometimes result in a loss of flexibility, making it difficult to adjust to surges in demand.

When a primary missile manufacturer produces an active missile for the United States, the firm utilizes suppliers to provide the needed inputs for the manufacturing process. Suppose that the President of the United States needs an inordinate number of missiles of a particular type, a JIT primary manufacturer will likely be unable to satisfy the demand. The reason is that the primary manufacturer's production process assumes a specific number of prescribed missiles will be manufactured every month or every year. Any significant or dramatic change in missile demand is unlikely to be met. For example, Raytheon Corp. currently manufactures approximately 600 Patriot missiles annually.[432] This number is expected to increase to 650 Patriot missiles per year in 2027.[433] In previous years, the number was as low as 350 missiles per year.[434] If the President of the United States needed 10,000 Patriot missiles in six months, the company could not meet the demand. It would take Raytheon Corp. approximately 16.7 years (= 10,000 missiles / 600 missiles per year) to satisfy the President's request. This is unacceptable.

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[422] Tracye Winfrey Howard, & Teresita Regelbrugge, DOD Issues Final Rule Addressing Conflicts of Interest in Certain Consulting Contracts, *Wiley Law* (Aug. 28, 2025), *available at* https://www.wiley.law/alert-DOD-Issues-Final-Rule-Addressing-Conflicts-of-Interest-in-Certain-Consulting-Contracts#:~:text=WHAT:%20The%20U.S.%20Department%20of,covered%20the%20proposed%20rule%20here.

[423] GAO Staff, Defense Acquisition Reform: Persistent Challenges Require New Iterative Approaches to Delivering Capability with Speed, *U.S. Government Accountability Office* (Jun. 11, 2025), *available at* https://www.gao.gov/products/gao-25-108528#:~:text=Why%20GAO%20Did%20This%20Study,Recommendations.

[424] *Id.*

[425] Caroline Banton, Just-in-Time (JIT): Definition, Example, Pros, and Cons, *Investopedia* (Feb. 22, 2025), *available at* https://www.investopedia.com/terms/j/jit.asp.

[426] *Id.*

[427] *Id.*

[428] *Id.*

[429] *Id.*

[430] Tamizh Inian, Can JIT Supply Chains Survive in an Era of Global Disruptions and Growing Challenges?, *Frigate* (Feb. 25, 2025), *available at* https://frigate.ai/business-model/can-jit-supply-chains-survive-in-an-era-of-global-disruptions-and-growing-challenges/#:~:text=JIT%20depends%20on%20accurate%20demand,costs%2C%20and%20extended%20lead%20times.

[431] *Id.*

[432] Evrim Ağaci, Patriot Missile Production Surges Amid Global Tensions, *Grand Pinnacle Tribune* (Aug. 10, 2025), *available at* https://evrimagaci.org/gpt/patriot-missile-production-surges-amid-global-tensions-487900.

[433] *Id.*

[434] *Id.*

Surge Capacity Issues for Selected United States Active Missiles

Lean Manufacturing Issues

According to Daniel, lean manufacturing, also known as lean production or lean, is "a methodology that focuses on minimizing waste within manufacturing systems while simultaneously maximizing productivity."[435] Waste is perceived as anything that customers do not believe adds value to the final product, or are unwilling to pay for.[436] The benefits of lean include reduced lead times, lower operating costs, and enhanced product quality.[437] The lean approach is based on TPS. Firms that employ enterprise resource planning (ERP) may also benefit from using a lean production system.[438] According to Womack and Jones, the five core principles of lean production are:[439]

- Identify value from the customer's perspective, not the producer's point of view;
- Map the value stream by recording and analyzing the flow of information or materials;
- Create flow by eliminating functional barriers and identifying ways to improve lead time;
- Establish a pull system rather than a push system; and
- Pursue continual process improvement, or Kaizen.

The eight wastes of lean production include:[440]

- Unnecessary transportation;
- Excess inventory;
- Unnecessary motion of people, equipment or machinery;
- Waiting, whether it is people waiting or idle equipment;
- Overproduction of a product;
- Over-processing, or investing more time in a product than a customer needs;
- Defects that require effort and cost for correction and
- Unused talent and ingenuity.

For primary missile manufacturers that employ lean production techniques, surge capacity is wasteful because it involves either people waiting or idle equipment. However, without surge capacity, missile manufacturers would be unable to meet dramatic increases in demand. Given the current global political environment, without some form of surge capacity, a primary missile manufacturer cannot adjust its manufacturing processes to respond to rapidly changing circumstances, where war or kinetic conflicts can break out at almost a moment's notice. Thus, lean manufacturing may adversely affect surge capacity. The more dedicated a primary missile manufacturer is to lean practices, the more challenging it becomes to respond positively to the demand for surge production.

Labor Force Issues

The active missile manufacturing industry, part of the aerospace and defense (A&D) sector, is facing an aging workforce, outdated training methods, and increasing demand for emerging, highly specialized skills.[441] Missile technology is becoming increasingly complex due to software, AI, and advanced manufacturing techniques.[442] The primary challenges are:[443]

- ***Aging workforce and knowledge transfer:*** A significant percentage of the A&D workforce is quickly approaching retirement, where as many as 25 percent are over age 55. This fact poses a significant risk of losing essential institutional knowledge and expertise. Effective knowledge transfer programs are urgently needed to reduce the skills gap.
- ***Skills mismatch:*** The issue is that the current workforce's skills do not necessarily support the needs of modern missile manufacturing. Although there is a high demand for skills in AI, cybersecurity, advanced manufacturing techniques, database administration, and software development, there is also a need for workers who understand and can implement simplified manufacturing techniques to reduce the requirement for a highly skilled workforce.

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[435] Diann Daniel, What Is Lean Manufacturing?, *Tech Target* (Apr. 29, 2025), *available at* https://www.techtarget.com/searcherp/definition/lean-production.
[436] *Id.*
[437] *Id.*
[438] *Id.*
[439] *Id.*
[440] *Id.*
[441] Derrick Ryskamp, Aerospace and Defense Industry's Demand for Talent Outpaces Supply, *ACARA* (Jan. 15, 2025), *available at* https://acarasolutions.com/blog/recruiting-trends/aerospace-and-defense-industrys-demand-for-talent-outpaces-supply/#:~:text=Factors%20Contributing%20to%20the%20Shortage,companies%20are%20implementing%20various%20strategies:.
[442] *Id.*
[443] *Id.*

- ***Outdated educational partnerships:*** The technical and community colleges often struggle to meet the educational demands of the missile manufacturing industry. Updating an educational program is a sluggish process, where relevant, real-time skills are often neglected.
- ***Ineffective on-the-job training (OJT):*** Traditional OJT methods are sometimes less effective in situations with high turnover and a scarcity of experienced supervisors needed to mentor new employees. Budgetary constraints often limit the availability of formal, career-oriented training, thereby causing new employees to seek employment elsewhere.
- ***Complicated and long security clearance process:*** The security clearance process can take eight months or longer. Offers are sometimes rescinded, and many new employees may decide that it is easier to be hired in the private sector.
- ***Insufficient cross-training:*** With a dearth of cross-training, manufacturing bottlenecks and rigid production schedules may occur, reducing missile manufacturing flexibility and efficiency.
- ***Intense competition for talent:*** The missile manufacturing sector competes with other high-tech industries for the same limited talent as sought by the private sector. Given that a technical education is a rare commodity these days, the ability to compete becomes even more intense.

Government and industry cooperation, revising educational outreach, encouraging partnerships and initiatives, and implementing targeted training programs are being used to mitigate the training issues experienced by the missile manufacturing industry.[444]

Union Relations Issues

In the missile manufacturing industry, unions pose two significant problems. First, unions typically seek strict, rigid work rules that specify who does what work.[445] These detailed rules are usually specified in collective bargaining agreements to protect workers from management favoritism, ensure safety, and prevent the devaluing and deskilling of experienced labor.[446] By the same token, strict work rules can generate inefficiencies, particularly when a lack of surge capacity hinders production.[447]

Second, union workers in the defense industry pose a conundrum for anti-war union activists.[448] For example, on November 9, 2023, dozens of protesters were outside the weapons company Colt Manufacturing in West Hartford, Connecticut, holding banners demanding that the genocide in Palestine be stopped. Colt was selected because it supplied 24,000 assault rifles destined for Israel.[449] Also on November 9, 2023, protesters conducted a “die-in” outside the offices of Lockheed Martin, a company that supplies missiles to Israel, while others demonstrated outside the Goleta, California, plant that belonged to Raytheon Corp, because Israel purchases missiles from the firm.[450] The issue is that union activities and relations can significantly affect a missile manufacturer’s ability to overcome the surge capacity problem.

EFFECTS OF THE SURGE CAPACITY PROBLEM

The five areas of concern when analyzing the effects of the surge capacity problems are:[451]

- Hierarchical structural issues;
- Psychosocial issues;
- Technical issues;
- Managerial issues; and
- Goals and objectives issues.

Structural issues affecting the entity's organizational hierarchy may result in slow communication and decision-making, a lack of employee autonomy and creativity, increased costs attributed to middle management, and departments' inability to foster

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444 Joseph Clark, DOD Is Taking Steps to Shore Up Industrial Workforce, *U.S. Department of Defense News* (Sep. 23, 2023), *available at* https://www.defense.gov/News/News-Stories/Article/Article/3540407/dod-is-taking-steps-to-shore-up-industrial-workforce/#:~:text=%22The%20industry%20over%20the%20next,into%20the%20same%20skill%20sets.%22.

445 Jenn Hagedorn, Claudia Alexandra Para, Howard Greenwich, & Amy Hagopian, 106 AMERICAN JOURNAL OF PUBLIC HEALTH 6, 989-95 (Jun. 2016), *available at* DOI: 10.2105/AJPH.2016.303138.

446 *Id.*

447 *Id.*

448 Jeff Schuhrke, The Problem of the Unionized War Machine, *Jewish Currents* (Nov. 22, 2023), *available at* https://jewishcurrents.org/the-problem-of-the-unionized-war-machine.

449 *Id.*

450 *Id.*

451 DONALD L. ANDERSON, ORGANIZATIONAL DEVELOPMENT: THE PROCESS OF LEADING ORGANIZATIONAL CHANGE (Sage Publications, Inc. 6th ed. Dec. 14, 2023).

collaboration and discourage rivalries.[452] The rigid, top-down nature of a corporate hierarchy creates these issues by discouraging workers and limiting their ability to respond to changing circumstances.[453] Psychosocial issues encompass a broad range of factors that influence an organization, including social, psychological, and environmental circumstances.[454]

A technical issue is typically a malfunction or some difficulty with technology, including hardware, software, networks, or processes, that prevents a missile from working correctly or as designed.[455] Managerial issues refer to management inadequacies, including planning, organizing, leading, and controlling.[456] Poor communication, team conflicts, understaffing, poor employee performance, inadequate resource allocation, a lack of clear direction or organizational structure, failure to provide proper feedback and recognition, and difficulty managing time are all common managerial issues.[457] These issues may impact productivity, morale, and overall corporate success, thereby contributing to the surge capacity problem.[458] Finally, goals and objectives often lack clarity, have unrealistic targets, inadequate measurement, resistance to change, fear of failure, and a lack of resources or support.[459] To address surge capacity issues effectively, it is essential to establish SMART objectives that align with an entity's broad goals. This involves fostering allegiance by periodically reviewing and adjusting plans to ensure they respond to changing situations.[460] [461]

The following subsections examine the impact of the surge capacity problem on the United States' defense system, the Israeli defense system, the Ukrainian defense system, the NATO defense system, and the defense systems of various United States allies. Some of the issues described above may not apply to a particular United States ally. However, the problem framework listed above is comprehensive and likely to be useful when exploring the impact of the surge capacity problem.

The Impact on the United States Defense System

The United States' defense industrial base is the epicenter of missile production, yet it faces acute surge vulnerabilities. For one thing, there are hierarchical structural issues. Primarily, Raytheon Corp. dominates the output of all five systems, creating single-source dependencies. Sub-tier suppliers for legacy systems, such as the AIM-7 Sparrow and the AGM-65 Maverick, have existed, and RIM-161 Standard Missile 3 production is closely tied to the Aegis BMD architecture, limiting scalability.[462] Additionally, there are psychosocial issues, as manufacturers hesitate to invest in surge tooling without multi-year contracts. Systems like AIM-7 Sparrow and AGM-65 Maverick are being phased out, while MIM-104 Patriot and the RIM-161 Standard Missile 3 are treated as limited-use systems. Add to this the technical issues. For example, the RIM-156A Standard and AIM-7 Sparrow systems suffer from obsolete electronics and non-modular propulsion.[463] RIM-161 Standard Missile 3 requires space-grade components and exo-atmospheric testing. The MIM-104 Patriot's radar-interceptor integration is complex and export-fragmented.[464] There are also managerial issues related to single-year contracting, workforce attrition, and surge planning. No active program offices exist for the

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[452] Jori Hamilton, Hierarchical va Flat Organizational Structures in the Workplace, *Jostle Blog* (n.d.), *available at* https://blog.jostle.me/blog/hierarchical-vs-flat-organizational-structures-in-the-workplace#:~:text=Cons%20of%20Hierarchical%20Organizational%20Structures&text=Increased%20business%20costs:%20The%20necessity,within%20the%20rank%20and%20file.

[453] *Id.*

[454] Hailay Tesfay Gebremariam, Million Desalegn Tassew, & Frehiwot Sahle Woldemaryam, Insights into Psychosocial Problems and Associated Factors Among Higher Education Students in Ethiopia: A Cross-Sectional Study, BMC PUBLIC HEALTH 24, 2784 (2024), *available at* https://doi.org/10.1186/s12889-024-20262-w.

[455] *See generally*, Aaron Sherrill, How to Identify a Tech Problem in 5 Steps, *Ten Hats* (May 23, 2024), *available at* https://tenhats.com/how-to-identify-a-tech-problem/#:~:text=What%20Is%20a%20"Tech%20Problem,measures%20to%20protect%20against%20cyberthreats.

[456] Jamie Birt, 12 Management Challenges and How To Overcome Them, *Indeed* (Jun. 6, 2025), *available at* https://www.indeed.com/career-advice/career-development/management-challenges.

[457] *Id.*

[458] *Id.*

[459] *See generally*, Rozana Barb, Goal-Setting: Strategies, Challenges and Mistakes, *The KPI Institute* (Nov. 5, 2020), *available at* https://www.performancemagazine.org/goal-setting-strategies-challenges-mistakes/#:~:text=Goals%20are%20too%20low:%20on,delivery%20time%20and%20government%20restrictions.

[460] *Id.*

[461] Charles E. Ziegler, A Russian-Chinese Partnership Against America?, *The National Interest* (Mar. 6, 2021), *available at* https://nationalinterest.org/feature/russian-chinese-partnership-against-america-179280.

[462] Seth G. Jones, The U.S. Defense Industrial Base Is Not Prepared for a Possible Conflict with China, *Center for Strategic and International Studies* (Feb. 22, 2023), *available at* https://features.csis.org/preparing-the-US-industrial-base-to-deter-conflict-with-China/.

[463] Norman Friedman, *supra*, note 81.

[464] *See generally*, Mark Nesline, John Linz, Martin Kenger, & Felicia Cook, Integration of the PAC-3 Missile Segment into the Patriot Air Defense System, *Defense Technical Information Center* (Aug. 1, 1996), *available at* https://apps.dtic.mil/sti/citations/ADA319953#:~:text=The%20system%20has%20evolved%20from,design%20which%20meets%20this%20goal.

AIM-7 Sparrow or the AGM-65 Maverick.[465] The RIM-161 Standard Missile 3 and MIM-104 Patriot require interagency coordination.[466] Finally, the issues with goals and objectives arise from strategic goals that emphasize deterrence and sustained conflict. Still, surge capacity is misaligned for legacy systems and only partially aligned for MIM-104 Patriot and RIM-161 Standard Missile 3.

The United States' defense industrial base faces significant challenges in scaling missile production under surge conditions. Although the AIM-7 Sparrow suffers from obsolete propulsion components, the same cannot be said for the MIM-104 Patriot system, which has been updated over time.[467] Raytheon's dominance across missile categories introduces a single point of failure, exacerbated by inconsistent demand signals and limited multi-year contracting.[468] These constraints undermine strategic depth and operational flexibility in extended engagements. Congressional appropriations have responded with increased funding for munitions, including over $30 billion in the FY2024 budget for long-range fires and industrial base revitalization.[469]

The Impact on the Israeli Defense System

Israel's missile defense posture is tightly coupled to the United States' supply chains through Foreign Military Sales and joint development programs. Surge constraints in systems such as the AIM-9 Sidewinder and FGM-148 Javelin pose a threat to Israel's ability to sustain high-tempo operations across multiple theaters.[470] The strategic depth afforded by rapid resupply is compromised when the United States' production cannot scale to meet demand. In response, Israel has accelerated domestic production and co-development initiatives, including Rafael's expansion of indigenous missile programs, while continuing to rely on the United States' foreign military financing (FMF) allocations.[471]

The surge capacity issues in the context of Israel's defense posture relate to Israel's reliance on a rapid multi-front response and the United States' missile resupply abilities. For Israel, the hierarchical structural issues exist because Israel fields MIM-104 Patriot and legacy AIM-7 Sparrow and AIM-9 Sidewinder stocks but lacks control over the United States' production hierarchies.[472] Surge capacity is influenced by external factors. In the case of psychosocial problems, growing skepticism about the reliability of the United States' surges has prompted investment in Rafael systems, such as the Iron Dome or Spike. The issue of technical difficulties, including variant divergence in the AIM-7 Sparrow and AGM-65 Maverick, complicates integration. MIM-104 Patriots' export configuration differs from the United States baseline, limiting interoperability.[473] Managerial Israeli issues include Israel's streamlined domestic acquisition, but imported systems depend on the United States' timelines and FMS bureaucracy, as well as Israeli goals and objectives. Surge delays in imported systems undermine Israel's strategic goal of rapid response.[474] Indigenous production is increasingly prioritized.

The Impact on the Ukrainian Defense System

Ukraine's defense against Russian aggression has exposed the brittle nature of Western munitions supply chains. Early reliance on systems such as the FGM-148 Javelin and the FIM-92 Stinger revealed long lead times and export control bottlenecks.[475] The United

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465 Norman Friedman, *supra*, note 81.

466 Alex Hollings, The Ultimate Guide to the Patriot Air Defense System, *Sandboxx* (Mar. 5, 2025), *available at* https://www.sandboxx.us/news/the-ultimate-guide-to-the-patriot-air-defense-system/#:~:text=Today%2C%20the%20Patriot%20is%20operated,as%20"defense%20in%20depth.".

467 Alex Hollings, Patriot Missile Explained: Inside America's Most Advanced Air Defender, *1945* (Mar. 8, 2025), *available at* https://www.19fortyfive.com/2025/03/patriot-missile-explained-inside-americas-most-advanced-air-defender/.

468 GAO Staff, Defense Industrial Base: Actions Needed to Address Risks Posed by Dependence on Foreign Suppliers, *GAO-25-107283* (July 2025), *available at* https://www.gao.gov/assets/gao-25-107283.pdf.

469 Sam Lagrone, FY 2024 Budget: Pentagon Asks for $30.6B to Beef Up Munitions Stockpile Citing Lessons from Ukraine War, *USNI News* (Mar. 14, 2023), *available at* https://news.usni.org/2023/03/14/fy-2024-budget-pentagon-asks-for-30-6b-to-beef-up-munitions-stockpile-citing-lessons-from-ukraine-war.

470 Bradley Martin, *supra*, note 20.

471 Jeremy M. Sharp, U.S. Foreign Aid to Israel: Overview and Developments since October 7, 2023, *Congressional Research Service* (May 28, 2025), *available at* https://www.congress.gov/crs-product/RL33222#:~:text=Under%20the%20terms%20of%20the,base%20level%20($3.3%20billion).

472 *Id.*

473 Citadel Staff, Patriot Air Defense System Highlights Integration with US Allies, *Citadel* (Sep. 4, 2025), *available at* https://centcomcitadel.com/en_GB/articles/ssc/features/2025/04/09/feature-03#:~:text=%E2%80%8BIn%20the%20ever-evolving,which%20Ukraine%20previously%20relied%20upon.

474 Jim Zanotti, Israel: Major Issues and U.S. Relations, *Congressional Research Service* (Dec. 5, 2024), *available at* https://www.congress.gov/crs-product/R44245.

475 ASB Staff, Surge Capacity in the Defense Munitions Industrial Base, *Army Science Board* (2023), *available at* https://asb.army.mil/Portals/105/Reports/2020s/ASB%20FY%2023%20DMIB%20Report%20%28E%29.pdf?ver=jZRw9v2VxCIqIvsBFsDG4g%3d%3d.

States Army Science Board identified surge capacity as a critical vulnerability, noting that shortages of propulsion and seeker components delayed replenishment and constrained battlefield effectiveness.[476]

Ukraine's wartime experience has exposed the apparent vulnerability of Western surge capacity related to the issues listed above. For Ukraine, hierarchical structural matters. Ukraine received AIM-7 Sparrow, AGM-65 Maverick, and MIM-104 Patriot systems donated by other countries, but the missiles lack integration into production hierarchies.[477] Donor fragmentation impedes coordination. In the case of psychosocial issues, surge delays have strained confidence in Western supply chains. Ukraine is pursuing NATO-standardization and domestic manufacturing.[478] Technical problems in legacy systems, such as AIM-7 Sparrow and AGM-65 Maverick, are challenging to sustain. MIM-104 Patriot integration is slowed by training and component shortages. The managerial issues include the lack of a unified acquisition framework and uneven, reactive deliveries. Maintenance and sustainment lack an operational tempo. Ukraine's goals and objectives, which involve sustained resistance, are misaligned with donors' surge capacity. External dependencies on the United States and NATO limit strategic autonomy.[479]

The Impact on the NATO Defense System

NATO's collective defense architecture depends on shared stockpiles and interoperable missile systems. Surge risks in high-end systems such as the RIM-161 Standard Missile 3 and AGM-158 JASSM threaten the alliance's ability to sustain operations beyond initial engagements.[480] [481] Article 5 scenarios require a rapid, multi-theater response, which is jeopardized by limited production scalability and centralized manufacturing. NATO has responded with initiatives such as the Defense Production Action Plan (DPAP) and the Defense Innovation Accelerator for the North Atlantic (DIANA), an organization established by NATO to identify and accelerate dual-use innovation capacity, thereby coordinating industrial scaling and reducing reliance on the United States' bottlenecks.[482]

In the case of NATO's collective defense, it depends on shared stockpiles and interoperability, particularly with the United States. The hierarchical structural issue for NATO implies that all its members should include an integrated air and missile defense system, Joint Intelligence, Surveillance, and Reconnaissance (JISR) system, standing maritime forces, NATO Communications and Information Agency (NCIA), and the NATO Support and Procurement Agency (NSPA), but procurement is decentralized, and no unified surge hierarchy exists.[483] For NATO, the psychosocial issues involve the eastern flank nations, particularly those near Russia, which are particularly concerned about a surge capacity.[484] The Western NATO members in the alliance before the collapse of the Soviet Union tended to see surge capacity as a lower priority.[485] That has created friction, especially when the United States' defense contractors prioritize exports, leaving some allies feeling sidelined. While NATO has worked to standardize systems like the MIM-104 Patriot and RIM-161 Standard Missile 3 across its member countries, export controls and differences in seeker technology remain a hindrance.[486] There is no central plan for surge coordination, and procurement varies widely from one member to another,

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[476] *Id.*

[477] Illia Ponomarenko, Patriot Air Defense Faces Its Toughest Challenge Ever in Ukraine, *The Kyiv Independent* (May 2, 2023), *available at* https://kyivindependent.com/patriot-air-defense-faces-its-toughest-challenge-ever-in-ukraine/.

[478] Kateryna Zakharchenko, Ukraine's Defense Sector Could Transform NATO: Alliance Official Affirms. *Kyiv Post* (Oct. 17, 2025), *available at* https://www.kyivpost.com/post/62352#:~:text=autonomous%20drone%20interceptors.-,Joint%20Ventures%2C%20direct%20investment%2C%20and%20export%20potential,a%20win-win%20situation.".

[479] Federico Mellace, Taro Nishikawa, & Jannis Stagge, A Fragile Surge: European Support to Ukraine in Early 2025 – New Insights from the Kiel Institute Ukraine Support Tracker, *De Gruyter Brill* (Aug. 29, 2025), *available at* https://www.degruyterbrill.com/document/doi/10.1515/ev-2025-0028/html#:~:text=Abstract,and%20more%20balanced%20burden-sharing.

[480] Armen Agas, NATO's Hypersonic Defense Problem Is Industrial, Not Technological, *Times-Leader* (Oct. 2, 2025), *available at* https://www.fairfieldsuntimes.com/opinion/nato-s-hypersonic-defense-problem-is-industrial-not-technological/article_add52f59-daab-5ec6-8d98-2568d3da1d1d.html.

[481] Seth G. Jones, *supra*, note 462.

[482] *Id.*

[483] NATO Staff, Collective Defence and Article 5, *North Atlantic Treaty Organization* (Jul. 4, 20923), *available at* https://www.nato.int/cps/fr/natohq/topics_110496.htm?selectedLocale=en#:~:text=and%20forward%20defences.-,Standing%20forces,the%20Algerian%20departments%20of%20France.

[484] Stanislaw Koziej, NATO Strategic Priorities, 10 Commandments, *GIS Reports Online* (Dec. 10, 2024), *available at* https://www.gisreportsonline.com/r/nato-defense-russia-deter-strategy/.

[485] NATO Staff, A Short History of NATO,. *North Atlantic Treaty Organization* (n.d.), *available at* https://www.nato.int/cps/ru/natohq/139339.htm#:~:text=During%20this%20time%2C%20NATO%20adopted,well%20as%20a%20military%20role.

[486] Praney Vaddi, Revising Missile Controls Is Necessary to Help Allies and Prevent New Nuclear States, *Center for Strategic & International Studies* (May 5, 2025), *available at* https://www.csis.org/analysis/revising-missile-controls-necessary-help-allies-and-prevent-new-nuclear-states#:~:text=Cat%20I%20technology%20includes%20missiles,be%20MTCR%20Cat%20I%20systems.

further complicating management challenges.[487] Initiatives like DIANA and the Defense Production Act are working to address this issue. NATO's core mission, laid out in Article 5, calls for a fast, multi-theater response, but right now, surge planning is not fully aligned across the alliance.[488] NATO's goals and objectives are summarized in NATO's Article 5 commitments, which require a rapid, multi-theater response; however, surge planning is not integrated across members.[489]

The Impact on the Defense Systems of Other United States Allies

These allies rely heavily on the United States' missile systems for regional deterrence. For example, the hierarchical structural issues involve all five systems being fielded or requested through the FMS. Allies lack control over the United States' production hierarchies and face long lead times. The most significant threats in this region are China and North Korea, which create urgency concerning the psychosocial issues.[490] The United States' export timelines and political sensitivities block a surge for systems like RIM-161 Standard Missile 3 and the MIM-104 Patriot, which require United States-based integration.[491] AIM-7 Sparrow and AGM-65 Maverick are legacy systems without domestic sustainment, which exacerbates technical issues. In Taiwan, a severe backlog due to managerial issues is evident in FMS delays and export licensing bottlenecks, which hinder surge activation.[492] Strategic goals, like Taiwan's 2027 readiness or Japan's Indo-Pacific deterrence, are misaligned with current surge capacity.[493] [494] The reliance on the United States' production results in Australia's Guided Weapons and Explosive Ordnance enterprise (GWEO) initiative, which aims to build surge capability for Australian defense manufacturers.[495]

Japan, South Korea, and Australia are exposed to risk because they depend heavily on United States-made weapons like the BGM-109 Tomahawk and AGM-84 Harpoon.[496] When tensions rise in the Indo-Pacific, these countries face limits in how quickly they can respond or send a clear strategic message, due to bottlenecks in surge production and supply.[497] These nations are investing in domestic missile programs and joint ventures, such as Australia's GWEO, to hedge against the United States' surge limitations.[498]

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[487] Stuart Dee, James Black, & Lucia Retter, Resourcing the Ramp-Up: NATO and the Challenge of a Coherent Industrial Response to Russia's War in Ukraine, *RAND Corp.* (Jul. 25, 2024), *available at* https://www.rand.org/pubs/commentary/2024/07/resourcing-the-ramp-up-nato-and-the-challenge-of-a.html.

[488] Charlie Devereux, What are NATO's Defence Obligations under Articles 4 and 5 of Its Treaty?, *Reuters* (Sep. 25, 2025), *available at* https://www.reuters.com/business/aerospace-defense/nato-articles-4-5-could-ukraine-war-trigger-alliance-defence-obligations-2025-09-25/.

[489] NATO Staff, NATO's Role in Defence Industry Production, *North Atlantic Treaty Organization* (Jun. 26, 2025), *available at* https://www.nato.int/cps/en/natohq/topics_222589.htm#:~:text=The%20Plan%20is%20facilitating%20aggregation,industrial%20and%20military%20cooperation.

[490] James Park, & Mike Mochizuki, The U.S.–Japan–South Korea Trilateral Partnership: Pursuing Regional Stability and Avoiding Military Escalation, *Quincy Institute* (Apr. 22, 2024), *available at* https://quincyinst.org/research/the-u-s-japan-south-korea-trilateral-partnership-pursuing-regional-stability-and-avoiding-military-escalation/#.

[491] Polaris Staff, Arsenal of Bureaucracy: How to Fix the U.S. Arms Sales Bottleneck, *Polaris National Security* (Jul. 3, 2025), *available at* https://polaris-us.org/updates/arsenal-of-bureaucracy-how-to-fix-the-u-s-arms-sales-bottleneck/.

[492] Kevin Ting-Chen Sun, & Howard Shen, Taiwan's Biggest Limitation in Defense Isn't Spending, It's Late Deliveries from U.S. Defense Companies, *War-on-the-Rocks* (Mar. 28, 2025), *available at* https://warontherocks.com/2025/03/taiwans-biggest-limitation-in-defense-isnt-spending-its-late-deliveries-from-u-s-defense-companies/#:~:text=Taiwan%20relies%20almost%20exclusively%20on,institutional%20support%20for%20arms%20investment.

[493] Dominic Minadeo, Army 20 Years Out from Sufficient Munitions Capacity, Driscoll Says, *Inside Defense* (Jun. 4, 2025), *available at* https://insidedefense.com/daily-news/army-20-years-out-sufficient-munitions-capacity-driscoll-says#:~:text=The%20Army%20would%20need%20at,Committee%20Chairman%20Mike%20Rogers...

[494] David Vergun, China's Military Buildup Threatens Indo-Pacific Region Security, *Secretary of the Air Force: International Affairs* (Apr. 9, 2025), *available at* https://www.safia.hq.af.mil/IA-News/Article/4151303/chinas-military-buildup-threatens-indo-pacific-region-security/#:~:text=China%20aims%20to%20dominate%20the,our%20adversaries%2C%22%20he%20said.

[495] U.S. Army Public Affairs, United States and Australia Ink Historic Defense Manufacturing Agreements, *United States Army* (Mar. 19, 2025), *available at* https://www.army.mil/article/283837/united_states_and_australia_ink_historic_defense_manufacturing_agreements#:~:text=These%20MOUs%20are%20a%20testament,Australia%20through%20the%20GWEO%20enterprise.

[496] Wikipedia Staff, Defense Industry of South Korea, *Wikipedia.org* (Dec. 9, 2025), *available at* https://en.wikipedia.org/wiki/Defense_industry_of_South_Korea#:~:text=The%20defense%20industry%20of%20South,world's%208th%20largest%20weapons%20exporter.

[497] Rupert Schulenburg, Sources of Scale: US and Indo-Pacific Allies' Defence-Industrial Cooperation, *International Institute for Strategic Studies* (Aug. 4, 2025), *available at* https://www.iiss.org/online-analysis/military-balance/2025/08/sources-of-scale-us-and-indo-pacific-allies-defence-industrial-cooperation/#:~:text=Supply%20concerns%20have%20driven%20Japan,China's%20substantial%20conventional%20missile%20arsenal.

[498] Bradley Martin, *supra*, note 20.

Surge Capacity Issues for Selected United States Active Missiles

A key strategic initiative for Australia is to adopt an FMS. An FMS increases surge capacity in rapidly reconfigurable manufacturing infrastructure, where throughput is scalable and has a high tolerance to product upgrades. When this is done, defense and emergency response will be available from the upgraded industrial environments. An FMS enables the use of innovative machinery, such as computer numerical control (CNC) tools and robot systems, which facilitate rapid transitions between products with minimal downtime.[499] Lowering changeover costs and lead times improves production output in response to sudden demand spikes.[500]. Automated guided vehicles (AGVs) and robotic tool changers support dynamic scaling, minimizing labor bottlenecks during surge events.[501]

An FMS provides manufacturers with the flexibility to adapt quickly. By linking control systems across production sites, they allow for real-time adjustments to schedules and workflows, which is compatible with just-in-time operations.[502] In the defense sector, FMS facilitates a seamless transition from routine production to urgent demands, such as ramping up production of missile parts, UAVs, or critical infrastructure. This means less downtime, fewer tooling changes, and a faster response when readiness matters most.[503] The objective of FMS is to bridge the defense industry from peacetime manufacturing to an increased production of urgent missile components, UAVs, or critical infrastructure with minimal retooling, thereby enhancing operational readiness and strategic agility.[504] This capacity for rapid, modular, and automated scale-up makes FMS a cornerstone of modern surge manufacturing strategies.

Organizational Mapping and Strategic Implications of the Surge Capacity Effects

The surge capacity problem is not merely a matter of throughput. It involves a deep-seated organizational dysfunction across structural, psychosocial, technical, managerial, and strategic domains. By mapping these five categories below to specific defense systems, the systemic fragility that undermines rapid scale-up during conflict is exposed. Table 18 illustrates how these issues manifest across the United States, Israel, Ukraine, NATO, and Indo-Pacific allies.

This mapping reveals that surge failure is not a technical anomaly, but a predictable outcome of an organization's misaligned design. To quantify surge viability, the Surge Readiness Index (SRI) scores missile systems across five dimensions: modularity, supplier depth, contracting agility, strategic alignment, and throughput elasticity. The scoring definitions and methodology are as follows:[505]

- ***Modularity:*** Ease of component substitution and upgrade.
- ***Supplier Depth:*** Number and resilience of sub-tier suppliers.
- ***Contracting Agility:*** Ability to activate surge contracts quickly.
- ***Strategic Alignment:*** Fit with current deterrence and operational goals.
- ***Throughput Elasticity:*** Capacity to scale production rapidly.

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[499] ARRK Staff, Innovative FMS: How Does Flexible Manufacturing System Work?, *ARRK North America* (May 15, 2024), *available at* https://us.arrk.com/innovative-fms-how-does-flexible-manufacturing-system-work/#:~:text=more%20about%20it!-,What%20is%20a%20Flexible%20Manufacturing%20System?,that%20manage%20the%20production%20processes.

[500] DOD Staff, Defense Additive Manufacturing Strategy, *U.S. Department of Defense* (2021), *available at* https://www.cto.mil/wp-content/uploads/2021/01/dod-additive-manufacturing-strategy.pdf.

[501] Dong Li, Bo Ouyang, Duanpo Wu, & Yaonan Wang, Artificial Intelligence Empowered Multi-AGVs in Manufacturing Systems, *Cornell University* (2019), *available at* https://arxiv.org/abs/1909.03373.

[502] ARRK Staff, *supra*, note 499.

[503] G. Manu, M. Vijay Kumar, H. Nagesh, D. Jagadeesh, & M. B. Gowtham, Flexible Manufacturing System: A Review, 8 INTERNATIONAL JOURNAL OF MECHANICAL AND PRODUCTION ENGINEERING RESEARCH AND DEVELOPMENT 2 (Apr. 2018), *available at* https://www.researchgate.net/publication/324841870_Flexible_Manufacturing_Systems_FMS_A_Review.

[504] Luke A. Nicastro, Primer: U.S. Industrial Base Policy, *Congressional Research Service* (Mar. 10, 2023), *available at* https://www.congress.gov/crs-product/IF11311.

[505] *See generally*, ASB Staff, Surge Capacity in the Defense Munitions Industrial Base, *United States Army* (Sep. 14, 2023), *available at* https://asb.army.mil/Portals/105/Reports/2020s/ASB%20FY%2023%20DMIB%20Report%20(E).pdf.

Surge Capacity Issues for Selected United States Active Missiles

Table 18. Five Categories Mapped to Specific Defense Systems

Defense System	Hierarchical Issues	Psychosocial Issues	Technical Issues	Managerial Issues	Goals/Objectives Issues
United States	Raytheon Corp. dominates with no active program offices	Legacy systems are psychologically retired	Obsolete electronics and seeker divergence	Single-year contracts with workforce attrition	Deterrence-centric goals are misaligned with replenishment needs
Israel	Surge gated by the United States production hierarchy	Skepticism regarding the United States' reliability with a shift to Rafael systems	Export variant divergence and limited interoperability	FMS bureaucracy and external timelines	Rapid response goals undermined by import delays
Ukraine	Donor fragmentation and no integration into the country's hierarchy	Eroded trust in Western supply chains	Legacy system sustainment challenges	Reactive deliveries and a lack of unified acquisition	Resistance goals are misaligned with the donor surge capacity
NATO	Decentralized procurement with no unified surge hierarchy	Eastern flank urgency versus Western complacency	Export restrictions and seeker divergence	No centralized surge coordination, where DIANA is still nascent	Article 5 requires a rapid response; surge planning is not integrated
Indo-Pacific Allies	FMS delays with no control over the United States' production	Urgency driven by China and North Korea threats	No domestic sustainment for legacy systems	Export licensing bottlenecks with an FMS backlog	Strategic timelines are misaligned with the surge

In Table 19, each dimension is assessed using a qualitative scale mapped to numeric values:

Table 19. Scoring Definitions Qualitative Scale

Dimension	Qualitative Scale	Numeric Value
Modularity (M)	Low / Medium / High	1 / 2 / 3
Supplier Depth (S)	Shallow / Moderate / Deep	1 / 2 / 3
Contracting Agility (C)	Low / Medium / High	1 / 2 / 3
Strategic Alignment (A)	Misaligned / Partial / Aligned	1 / 2 / 3
Throughput Elasticity (T)	Rigid / Moderate / High	1 / 2 / 3

The Raw Score is calculated as the sum of all five dimension values and is normalized to an SRI score between one and five. Sample results for active legacy missiles are contained in Table 20.

The SRI framework enables defense planners to prioritize investment and reform by identifying systems most vulnerable to surge failure. For example, the AIM-7 Sparrow and AGM-65 Maverick score lowest due to their outdated architecture and limited supplier networks, whereas the RIM-162 Evolved Sea Sparrow and MIM-104 Patriot score higher due to their modularity and strategic alignment.

These findings align with recent analyses from the Center for Strategic and International Studies, which emphasize the need for anticipatory surge modeling and industrial base revitalization to deter conflict with China.[506] RAND's commentary further underscores the psychosocial and managerial barriers to surge activation, particularly in allied systems.[507] The Army Science Board has identified propulsion and seeker shortages as critical vulnerabilities in Ukraine's munitions pipeline.[508] NATO's Defense

[506] Seth G. Jones, *supra*, note 462.
[507] Bradley Martin, *supra*, note 20.
[508] ASB Staff, *supra*, note 475.

Production Action Plan and DIANA initiative represent managerial remedies, but remain nascent.[509] Finally, the Department of Defense's Manufacturing Technology Strategic Plan advocates for flexible, automated production architectures to enable rapid scale-up.[510]

Table 20. Surge Readiness Index

System	Modularity	Supplier Depth	Contracting Agility	Strategic Alignment	Throughput Elasticity	SRI Score (1–5)
AIM-7 Sparrow	Low	Shallow	Low	Misaligned	Rigid	1
AGM-65 Maverick	Low	Shallow	Low	Misaligned	Rigid	1
RIM-161 Standard Missile 3	Medium	Moderate	Medium	Partial	Moderate	3
RIM-162 Evolved Sea Sparrow	High	Moderate	Medium	Aligned	Moderate	4
MIM-104 Patriot	Medium	Deep	Medium	Aligned	Moderate	4

`The dramatic increase in destroyer build time from roughly three to six months, with some as quickly as three months, during World War II,[511] to three to five years from contract to delivery today,[512] is driven by a convergence of technological complexity, industrial constraints, and strategic design philosophy.[513] During World War II, the United States' shipyards produced Fletcher-class destroyers in about 100 days. The wartime economy operated under total mobilization, with simplified designs and a labor force dedicated to mass production.[514]

Today, it takes two to three years to construct the Arleigh Burke-class Flight III, which is an advanced Aegis destroyer. The causes are:

- **Technological Complexity**: Aegis destroyers integrate Aegis combat systems, SPY-6 radar arrays, vertical launch systems, and advanced propulsion, all requiring precision engineering, software integration, and extensive testing.[515]
- **Labor and Supply Chain Constraints**: The United States' shipyards currently struggle to maintain skilled labor pools and face persistent supply chain bottlenecks. The Office of the Secretary of Defense noted that even producing two destroyers per year strains current capacity.[516]
- **Strategic Design Philosophy**: Unlike World War II's modular mass production, today's destroyers are built for multi-domain operations, survivability, and lifecycle upgrades requiring longer lead times and more intricate construction sequences.[517]
- **Industrial Base Fragmentation**: Only two shipyards, Bath Iron Works and Ingalls Shipbuilding, construct Arleigh Burke-class destroyers. Both have faced backlogs, workforce attrition, and pandemic-related delays.[518]

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[509] NATO Staff, Updated Defense Production Action Plan, *North Atlantic Treaty Organization* (Feb. 13, 2025), *available at* https://www.nato.int/cps/en/natohq/official_texts_236518.htm.
[510] DOD Staff, *supra*, note 500.
[511] Robert J. Cressman, Fletcher I (DD-445): 1942-1969, *Naval History and Heritage Command* (Apr.3, 2018), *available at* https://www.history.navy.mil/research/histories/ship-histories/danfs/f/fletcher.html.
[512] U.S. Navy Staff, DDG 51 Arleigh Burke Class Destroyers, *United States Navy* (Jan. 15, 2020), *available at* https://www.navsea.navy.mil/Portals/103/Documents/Exhibits/SNA2020/SNA2020-DDG51-CaptSethMiller.pdf?ver=2020-01-15-154402-527.
[513] Ronald O'Rourke, DDG-51 and DDG-1000 Destroyer Programs: Background and Issues for Congress, *Congressional Research Service* (Mar. 2023), *available at* https://www.congress.gov/crs-product/RL32109.
[514] NORMAN FRIEDMAN, U.S. DESTROYERS: AN ILLUSTRATED DESIGN HISTORY, 248–52 (Naval Institute Press 1982).
[515] Ronald O'Rourke, *supra*, note 513.
[516] *Id.*
[517] *Id*
[518] *Id*

Surge Capacity Issues for Selected United States Active Missiles

- **Global Naval Competition**: While China's shipyards produce large destroyers (e.g., Type 055) at faster rates, the United States prioritizes quality, interoperability, and strategic reach over raw hull count.[519]
  Another motivation is that the DOD deliberately paces the production of primary platforms, such as destroyers, submarines, and missile systems, to maintain the viability of key defense firms and shipyards. This approach ensures:
- **Workforce retention**: A steady production rhythm helps retain skilled labor, especially welders, engineers, and systems integrators, whose expertise is not easily replaced.[520]
- **Facility utilization**: Shipyards like Bath Iron Works and Ingalls Shipbuilding rely on consistent contracts to justify infrastructure investment and avoid mothballing.[521]
- **Surge readiness**: By keeping production lines warm, the DOD preserves the ability to scale output rapidly during conflict or crisis. Cold-starting a dormant line could take years.
- **Strategic autonomy**: Sustaining domestic capacity reduces reliance on foreign suppliers and preserves national security in critical sectors like propulsion, radar, and missile integration.[522]
- **Political and economic stability**: Defense contracts support regional economies and congressional districts, making them politically resilient and economically stabilizing.[523]

This logic is codified in acquisition strategies that favor multi-year procurement, incremental upgrades, and block buys. For example, the Navy's FY2023–2027 plan includes a steady-state purchase of two Arleigh Burke-class destroyers per year, not because that is the fastest possible rate, but because it sustains the industrial base without overloading it.[524] The United States Navy lost a total of 71 destroyers during World War II, with peak losses occurring between 1942 and 1944. This averages approximately 18 destroyers per year during the most intense years of combat.[525] The United States is not currently suffering such losses. Thus, the shift from rapid wartime production to deliberate peacetime construction reflects not inefficiency, but a recalibration toward capability, survivability, and strategic deterrence.

Catalysts for Missile Production Surge

Recent global developments have underscored the strategic need for surge-capable missile production. Geopolitical tensions, operational depletion, and industrial recalibration mitigate the limitations in surge capacity. The first driver, sustained high-tempo conflicts like the Russo-Ukraine war, has exposed the vulnerability of static munition inventories. United States officials observed that consumption rates of precision-guided munitions outpaced replenishment capacity.[526] This demanded urgent reassessment of stockpile adequacy and production throughput. This operational strain has catalyzed a shift from incremental procurement to industrial readiness, with the Pentagon targeting a 2.5-fold increase in missile production over a six- to 24-month horizon.[527] Key systems include the RIM-174 Standard ERAM, AGM-158 JASSM, AGM-158C LRASM, and MIM-104 Patriot variants, each requiring complex supply chains and multi-year build cycles. [528]

Secondly, Russia's and Ukraine's economies are operating under wartime footing. Russia, for example, has restructured its defense-industrial base to produce 200 Iskander-class missiles annually, alongside dramatic increases in artillery and armored

[519] Ryan Chan, U.S. Modernizes Naval Fleet As China Leads Shipbuilding Race, *Newsweek* (Aug. 2025), *available at* https://www.newsweek.com/us-modernizes-naval-fleet-as-china-leads-shipbuilding-race-10795548.
[520] Ronald O'Rourke, U.S. Navy Shipbuilding Outlook, *Congressional Research Service* (Sep. 2025), *available at* https://crsreports.congress.gov/product/pdf/RL/RL32665.
[521] Mallory Shelbourne, OSD Comptroller: U.S. Shipyards Can't Build 3 Destroyers a Year, *USNI News* (Mar. 21, 2023), *available at* https://news.usni.org/2023/03/21/osd-comptroller-says-u-s-shipyards-cant-build-3-destroyers-a-year.
[522] Gregory C. Allen, & Doug Berenson, Why Is the U.S. Defense Industrial Base So Isolated from the U.S. Economy?, Center for Strategic & International Studies (Aug. 20, 2024), *available at* https://www.csis.org/analysis/why-us-defense-industrial-base-so-isolated-us-economy.
[523] Brookings Staff, Defense Spending in the States, Brookings Institution (Apr. 28, 2023), *available at* https://www.brookings.edu/events/defense-spending-in-the-states/.
[524] Dong Li, Bo Ouyang, Duanpo Wu, & Yaonan Wang, *supra*, note 501.
[525] SAMUEL W. BRYANT, THE SEA AND THE STATES - A MARITIME HISTORY OF THE AMERICAN PEOPLE 569 (Thomas Y. Crowell Company, 1947).
[526] Wilson Beaver, & Jim Fein, America Must Remedy Its Dangerous Lack of Munitions Planning, *The Heritage Foundation* (Feb. 26, 2024), *available at* https://www.heritage.org/defense/report/america-must-remedy-its-dangerous-lack-munitions-planning#:~:text=the%20Indo–Pacific.-,Since%20the%20end%20of%20the%20Cold%20War%2C%20the%20U.S.%20has,ability%20to%20fight%20future%20wars.
[527] Ben Ward, Pentagon Seeks Surge in Missile Production Facing China Challenges, *Orbital Today* (Oct. 1, 2025), *available at* https://orbitaltoday.com/2025/10/01/pentagon-seeks-surge-in-missile-production-facing-china-challenges/.
[528] *Id.*

vehicle output.[529] This surge posture is reinforced by strategic partnerships with Iran and North Korea, forming a resilient Axis of Arms Production capable of outpacing Western arsenals.[530]

Ultimately, the Indo-Pacific theater serves as a focal point for deterrence-driven expansion. United States planners anticipate that a protracted conflict with China would probably rapidly exhaust current missile inventories. In response, the Department of Defense has activated the Munitions Acceleration Council and initiated weekly coordination with prime contractors to expand facilities, streamline licensing, and secure private investment.[531]

These developments reflect a broader doctrinal shift: from reactive procurement to anticipatory surge modeling. The emphasis is no longer solely on technological superiority, but on sustained throughput, diversified portfolios, and strategic depth in missile readiness.

Surge Drivers for Legacy and Integrated Missile Systems

The need for surge production of legacy and integrated missile systems often reflects a confluence of tactical depletion, platform integration, and threat evolution. For example, as one of the most widely produced precision-guided air-to-ground missiles in the Western arsenal, the AGM-65 Maverick remains relevant for close air support and tactical interdiction.[532] Surge demand may arise from attrition in low-intensity conflicts, export replenishment for partner air forces, or retrofitting legacy aircraft with updated Maverick variants. Its versatility against armor, air defenses, and infrastructure makes it a staple in regional deterrence packages.[533]

Second, although superseded mainly by the AIM-120 AMRAAM in air-to-air roles, the AIM-7 Sparrow remains in use in naval adaptations, such as the RIM-7 Sea Sparrow and RIM-162 Evolved Sea Sparrow. The replenishment of allied stockpiles may trigger surge production, integration into legacy platforms, or the use of interim solutions during AIM-120 AMRAAM shortages.[534] Third, the RIM-161 Standard Missile 3 is central to ballistic missile defense (BMD) architectures, particularly in Aegis-equipped naval platforms.[535] Surge triggers include heightened missile threats from North Korea and Iran, expansion of Indo-Pacific BMD coverage, and NATO deployments in response to Russian strategic systems. The RIM-161 Standard Missile 3's exo-atmospheric intercept capability makes it indispensable for layered defense.[536]

Fourth, designed to counter supersonic anti-ship missiles, the RIM-162 Evolved Sea Sparrow is a critical component of a ship's self-defense. Surge demand may stem from increased naval deployments in contested littorals (e.g., the South China Sea, the Red Sea), the modernization of NATO fleets, and Block 2 upgrades featuring dual-mode seekers and enhanced agility.[537] Finally, the MIM-104 Patriot system remains the backbone of the United States and allied ground-based air and missile defense. Surge production is often driven by active use in conflict zones, such as Ukraine or Israel, expanded deployments in Eastern Europe and East Asia, and integration with the MIM-104 Patriot PAC-3 interceptors for enhanced ballistic missile defense.[538] These systems, while varying in age and architecture, share a common surge logic: they are either actively consumed in current theaters, integrated into enduring platforms, or required for allied interoperability. The need to address surge capacity issues thus reflects both tactical needs and strategic signaling.

Structural Fragility and Improving Surge Capacity

The surge capacity problem is not a technical anomaly, but a predictable consequence of institutional design failure. Across the United States, Israeli, Ukrainian, NATO, and Indo-Pacific defense systems, the inability to scale production under pressure stems

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[529] Mackenzie Eaglen, Russia and China's Military Production Surge: Why the U.S. Military Is Alarmed, *American Enterprise Institute* (Apr. 8, 2025), *available at* https://www.aei.org/op-eds/russia-and-chinas-military-production-surge-why-the-u-s-military-is-alarmed/.
[530] *Id.*
[531] Daily Times Staff, Pentagon Pushes Missile Surge Amid China Tensions, *Daily Times* (Sep. 29, 2025), *available at* https://dailytimes.com.pk/1376219/pentagon-pushes-missile-surge-amid-china-tensions/.
[532] Prajesh Majumdar, Precision Strikes and the Dominance of the AGM-65 Maverick Missile, *Geeks* (2023), *available at* https://vocal.media/geeks/precision-strikes-and-the-dominance-of-the-agm-65-maverick-missile.
[533] U.S. Air Force Staff, *supra*, note 102.
[534] Dario Leone, A-10 Pilot Explains Why Warthog Drivers Often Boresight the AGM-65 Maverick on Wingman Rather Than on a Ground Target, Aviation Geek Club (Dec. 27, 2021), *available at* https://theaviationgeekclub.com/a-10-pilot-explains-why-warthog-drivers-often-boresight-the-agm-65-maverick-on-wingman-rather-than-on-a-ground-target/.
[535] CSIS Staff, *supra*, note 216.
[536] NAVAIR Staff, Air Intercept Missile AIM-7 Sparrow, *NAVAIR* (n.d.), *available at* https://www.navair.navy.mil/product/Air-Intercept-Missile-AIM-7-Sparrow.
[537] Raytheon Staff, Raytheon Standard Missile-3 Block IIA (SM-3 Block IIA) Achieves Full-rate Production Approval, *MilitaryLeak.com* (Oct. 19, 2024), *available at* https://militaryleak.com/2024/10/19/raytheon-standard-missile-3-block-iia-sm-3-block-iia-achieves-full-rate-production-approval/.
[538] Jen Judson, Raytheon Aims to Boost SM-3 Missile Production Rates, *Defense News* (Jan. 15, 2025), *available at* https://www.defensenews.com/naval/2025/01/15/raytheon-aims-to-boost-sm-3-missile-production-rates/.

from five interlocking dysfunctions: hierarchical rigidity, psychosocial inertia, technical obsolescence, managerial bottlenecks, and misaligned strategic objectives. These are not isolated issues. They are systemic, persistent, and quantifiable.

The SRI exposes this fragility. Legacy systems like AIM-7 Sparrow and AGM-65 Maverick score lowest, either because they are tactically irrelevant or because their architecture, supplier networks, and program offices have been allowed to atrophy. Meanwhile, systems like the RIM-162 Evolved Sea Sparrow and MIM-104 Patriot perform better, but even they are constrained by export fragmentation, interagency friction, and inconsistent demand signals. The problem is not just throughput. It is the absence of a coherent surge doctrine.

The United States' defense posture is built around deterrence, forward presence, and multi-domain dominance.[539] However, deterrence likely grows weaker as replenishment lags. Steady-state production, single-source dependencies, and boutique contracting cannot support high-tempo conflict. Raytheon's dominance across missile categories introduces a single-point-of-failure risk. Sub-tier suppliers are brittle. Multi-year contracts are rare. Surge tooling is probably underfunded. And program offices for legacy systems are likely either dormant or nonexistent. Israel's posture is more agile but externally gated. Ukraine is reactive and donor-fragmented. NATO is decentralized and politically uneven. Indo-Pacific allies face strategic urgency but lack control over production timelines. Although surge capacity shortfalls are not unexpected, they probably reflect inherent systemic vulnerabilities.

According to Pollard and Fein, reform should probably be structural, not cosmetic, suggesting that the Defense industry should take the following steps:[540]

- Flattening hierarchies to accelerate decision-making and eliminate middle-management drag.
- Revalidating legacy systems for surge utility instead of psychologically retiring them.
- Investing in modular architecture, automated tooling, and supplier depth.
- Embedding surge clauses into every major contract.
- Aligning strategic goals with replenishment realities. Deterrence without throughput is theater.

The DOD's Manufacturing Technology Strategic Plan (MTSP) and Additive Manufacturing Strategy (AMS) provide a blueprint. However, implementation is slow and fragmented. DIANA and NATO's Defense Production Action Plan are promising, but still in their embryonic stages. The Pentagon's Munitions Acceleration Council (PMAC) recognizes the problem, but without enforceable metrics, it is just another bureaucracy. Surge capacity is not a contingency but a core function. If the United States and its allies cannot scale missile production in real time, they will lose strategic depth, operational flexibility, and deterrence credibility. As RAND made clear, "[i]f the [United States] and its allies cannot scale missile production in real time, they will lose strategic depth, operational flexibility, and deterrence credibility."[541] This is not hypothetical but also a doctrinal fault line. The RAND report Inflection Point outlines how surge incapacity erodes readiness and exposes allied vulnerabilities in extended engagements.[542] The SRI framework is diagnostic and prescriptive, identifying where to invest, where to retire, and where to reform. This is not about efficiency. It is about survivability in the next conflict, and the clock is ticking.

SUGGESTIONS TO RESOLVE THE SURGE CAPACITY PROBLEM

In this section, twenty suggestions are discussed. Each suggestion deals with one or more of the causes highlighted in the possible causes section above. It is assumed that no single suggestion will fix the surge capacity problem by itself. To mitigate or even solve the surge capacity issue, multiple suggestions will likely need to be implemented. The surge capacity problem is a complex issue that requires fixing on multiple levels. Thus, the need for multiple proposed suggestions is paramount.

Suggestion #1: Do Nothing

This suggestion assumes that the surge-capacity problem will resolve itself once active missiles are no longer needed. This alternative could occur if hostilities in the various parts of the world were to end. Although this alternative is unlikely, it remains possible that combatants could reach a peaceful resolution in conflicts such as the Russian-Ukrainian War and the Israeli-Iranian conflict. Even so, this alternative is included to ensure the list of suggestions is comprehensive.

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[539] Melanie W. Sisson, What Is Deterrence, and What Is Its Role in U.S. National Defense?, *Brookings Institution* (May 1, 2024), *available at* https://www.brookings.edu/articles/what-is-deterrence-and-what-is-its-role-in-u-s-national-defense/#:~:text=The%20deterrence%20job%20of%20the,States%20or%20its%20treaty%20allies.

[540] Miles Pollard & Jim Fein, 5 Ways to Restore America's Defense Industrial Base, *The Hill* (Jan. 2025), *available at* https://thehill.com/opinion/national-security/5311852-defense-industrial-base-revitalization/.

[541] David A. Ochmanek, Anna M. Dowd, Stephen J. Flanagan, Andrew R. Hoehn, Jeffrey W. Hornung, Michael J. Lostumbo, & Michael J. Mazarr, Inflection Point: How to Reverse the Erosion of U.S. and Allied Military Power, *RAND Corp.*(Jul. 25, 2023), *available at* https://www.rand.org/pubs/research_reports/RRA2555-1.html.

[542] *Id.*

Suggestion #2: The President Declares Martial Law

Although the prospect of martial law may, on its face, appear attractive because it could suspend city, state, and federal laws and regulations that could impede primary missile manufacturers' ability to produce active missiles expeditiously, it does not take into account the physical limitations of a manufacturing facility. Suppose the machines engaged in the manufacturing process are insufficient to meet the demand specified by the federal government. In that case, martial law is ineffective in solving the surge capacity problem on an ongoing basis. It is critical to understand that martial law may solve the immediate surge-capacity puzzle, but could result in long-term issues stemming from an authoritarian solution after the initial crisis is over. Other Suggestions may be explored to achieve a lasting resolution.

Suggestion #3: Significantly Increase Competition

This suggestion proposes mitigating the surge capacity problem by increasing the number of primary missile manufacturers. This suggestion was implemented during World War II, and the result was that the United States was outproducing both Germany and Japan. How can this be accomplished? It depends on whether the United States or one or more of the three primary missile manufacturers, Raytheon Corp., Lockheed Martin Corp., or The Boeing Company, owns the relevant missile patents. If the United States owns the patents, the nation can license their use to other companies. If one or more of the three companies listed above own the patents, the companies could license them to other firms. If both the United States and one or more of the organizations own the relevant patents, then a decision could be made to license them to third-party manufacturers. If the missile technology is a trade secret, the primary missile manufacturer could license it to a third-party manufacturer.

From an economic standpoint, an increase in the number of primary missile manufacturers would mean declining profit margins. This can be observed by comparing a more competitive market with a highly concentrated oligopoly; Figure 3 shows the profit of an oligopolistic firm.

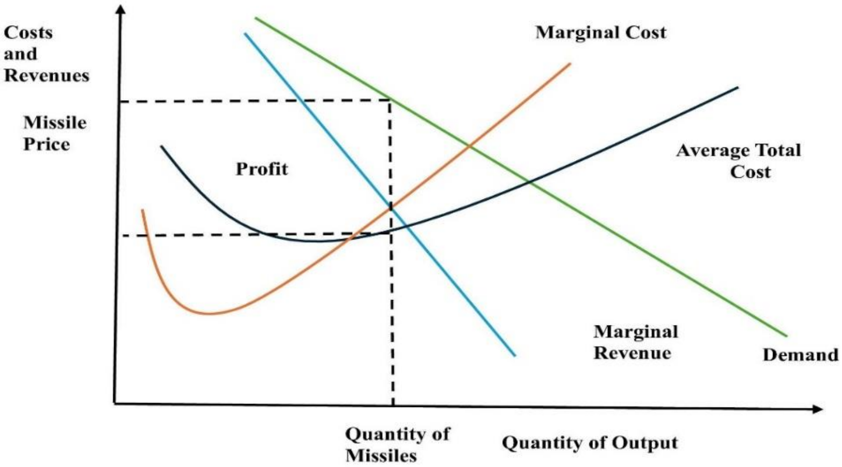

Figure 3. Profit of a Firm in a Concentrated Oligopoly

In contrast, when the primary missile manufacturing market is more competitive, there are more than three companies in the market, as can be seen in Table 17. In this instance, the marginal revenue curve is much closer to the demand curve. Figure 4 depicts this situation.

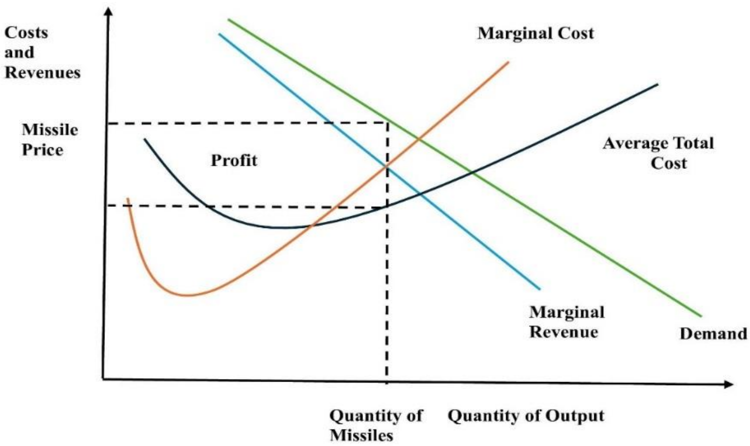

Figure 4. Profit of a Firm in a Competitive Market

Surge Capacity Issues for Selected United States Active Missiles

When comparing the graphs in Figure 3 and Figure 4, it is evident that as a market becomes more competitive and the marginal revenue approaches the demand curve, an individual firm's profit decreases, while the price of a missile decreases and the quantity of missiles produced increases. The decline in profits is detrimental to a primary missile manufacturer. However, the benefit to the United States government is that the price per missile declines while the number of missiles produced rises, thereby reducing the impact of the surge capacity problem. This benefit is evident in the production of military equipment during World War II. As more companies engaged in manufacturing bullets, rifles, tanks, airplanes, and other military equipment, the sheer volume of military hardware assured victory for the United States.

Second, and probably more importantly, Table 13 shows that Raytheon Corp. has a 75.01 percent market share, with an HHI index of 5,858.79, indicating a concentrated oligopolistic industry in the missile manufacturing sector. What would happen if Raytheon Corp. fell victim to a cybersecurity attack with kinetic consequences, if a terrorist organization kinetically attacked the company, or if the firm experienced a union strike at an inopportune moment? There is a possibility that Raytheon Corp. would be unable to continue producing missiles at the rate demanded by the federal government. This would have a dramatic effect on the United States' ability to wage war or to provide its allies with missiles when needed. Simply stated, these potential scenarios are unacceptable.

Suggestion #4: Reduce Excessive City Ordinances, State Laws, and Regulations

The reduction of city and state laws and regulations that prevent a missile manufacturer from increasing its production facilities is usually due to zoning ordinances or state laws that, for a variety of reasons, inhibit a firm's expansion. Suppose a surge capacity problem exists, and there is a substantial demand for active missiles from the federal government or foreign governments. In that case, the missile manufacturer can petition the city or state for either a temporary exemption or suspension of the city ordinances, state laws, or regulations, or lobby for their repeal. Although repealing a city ordinance, state law, or regulation may take some time to achieve, a temporary exemption or suspension is usually much easier to attain. Political and social support may influence implementation in ensuring that this suggestion is effectively implemented in a timely manner.

Suggestion #5: Decrease Federal Laws, Regulations, and International Treaties

As stated in Suggestion #4, federal laws and regulations can be modified when there is a sense of urgency in quickly manufacturing a large volume of active missiles. Congress is typically responsive to the nation's national security needs. Members of Congress and federal regulators are loath to be seen as being against defending the country. This means that if there is a genuine need for a significant number of additional active missiles, Congress and federal regulators will likely approve modifications to the laws and regulations that currently inhibit a primary missile manufacturer from advancing the country's military hardware needs.

However, international treaties are a different matter. Foreign countries do not necessarily share the same military goals and objectives as those of the United States. International treaties typically require several years of complex negotiations to reach a mutually acceptable agreement among all signatories.[543] In many instances, there are serious consequences to withdrawing or denouncing a treaty. By withdrawing from a treaty, a party may implicitly acknowledge that the other parties are also exempt from the treaty's obligations. The result may be that economic and political tensions increase among the former signatories, thereby reducing trade and international cooperation.

Suggestion #6: Expedite Expansion of Physical Facilities

Assuming that a primary missile manufacturer can obtain the necessary permits, it is possible to increase production capacity by expanding its physical facilities. This suggestion cannot be achieved in a short time period. New construction takes time, and the more square footage is added, the longer it takes to expand the physical facilities. Substantial physical plant additions usually take at least a year or more to complete, depending on the size of the workforce. This is not necessarily a short-run suggestion, but rather one that may take several years to complete. It is essential to remember that not only will the new facilities be constructed, but they should also be seamlessly integrated into the existing manufacturing plant(s). Meticulous planning and implementation are essential when bringing this suggestion to fruition.

Suggestion #7: Convert Existing Manufacturing Facilities

Suggestion #7 assumes that a primary missile manufacturer makes no effort to build additional production facilities. Instead, it converts existing facilities to produce a designated active missile. This may not be easy to accomplish if there are significant differences between the old missile being scrapped and the new missile to be manufactured in these existing facilities. It may turn out that production machinery for the old missile is moved to another manufacturing plant, but the more likely scenario is that the

[543] Michael Wood, The Negotiation of Multilateral Treaties at the United Nations: A NEGOTIATOR'S VIEW, IN THE OXFORD HANDBOOK OF UNITED NATIONS TREATIES 615 (Oxford Univ. Press 2019), *available at* DOI: 10.1093/law/9780190947842.003.0037.

old missile manufacturing equipment is sold for scrap. It may turn out that the old missile manufacturing machines can be converted to produce the new active missile, but this depends on the new missile's manufacturing needs.

In any case, Suggestion #7 assumes that the existing manufacturing facilities can completely contain the production of the new missile. This can only happen when the old plant has more square footage than is needed to produce the new missile. It should be remembered that when converting a manufacturing facility to produce a new active missile, the utilities (e.g., electrical wiring, heating, air conditioning, etc.) will likely require either no changes to their current configuration or only minor changes. Because the converted facilities require no additional square footage construction, the local permits to make the needed utility configuration changes are likely minimal.

Suggestion #8: Increase Innovation by Using Simplified Technologies

Suggestion #8 is interesting because it deals with ways to simplify the operation of active missiles. The idea behind this suggestion is to utilize technologies that are easy to manufacture because they involve fewer moving parts. One way to simplify the manufacturing process is to automate missile production using robots, rather than relying on manual efforts. Missile production could be viewed from the perspective of manufacturing automobiles, where robots are used extensively.[544] By utilizing reprogrammable robots, different active missiles could be manufactured using the same robots. In this way, welds could be uniformly performed, and waste could be efficiently handled and minimized. The technology is simplified because variations present when humans are part of the production process can be eliminated or drastically reduced.

Suggestion #9: Reduce Unneeded Missile Complexity

As missile technology advances, missile complexity is likely to increase. One way to reduce missile technology is to review a missile's design and look for unnecessary redundancies. This may be accomplished by employing artificial intelligence (AI) programs.[545] [546] AI can reduce the complexity of a missile system by restructuring its development, enhancing in-flight performance, and optimizing command-and-control functions.[547] By handling and automating complex tasks, AI suggests that missiles are more flexible and reliable, while also reducing issues with human operators and supporting systems.[548]

In manufacturing and testing, AI can streamline the expensive, complex design and testing phases of missile development by reducing the need for physical prototypes and lengthy development cycles.[549] This includes "digital twins" to simulate performance under real-world conditions, such as evading missile defenses or striking mobile targets.[550] AI can also enable a large number of test scenarios to be run virtually, identifying potential issues and refining a missile design before a physical prototype is constructed, thereby reducing development time, costs, and manufacturing overhead.[551] Finally, AI guidance and control systems can make missiles more adaptive and precise by reducing the complexity of their internal programming and hardware. AI can enhance targeting mechanisms, optimize hypersonic trajectories, and orchestrate multiple missile engagements.[552]

Suggestion #10: Promote Disruptive Engineering Technologies

Suggestion #10 is similar to Suggestion #8. When considering this suggestion, a primary missile manufacturer searches for simplified engineering technologies in their quest to decrease costs while increasing production effectiveness and efficiency. It is

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[544] Spatial Team, Discover How Automotive Robots Are Used in Car Manufacturing, *Spatial* (Jul. 9, 2023), *available at* https://blog.spatial.com/automotive-robots#:~:text=Robots%20play%20a%20crucial%20role,human%20workers%20and%20the%20environment.

[545] Julian I. Jones II, Russell Kress, William J. Newmeyer Jr., & Adam I. Rahman, Leveraging Artificial Intelligence (AI) For Air And Missile Defense (AMD): An Outcome-Oriented Decision Aid, *Naval Post Graduate School* (Sep. 2020), *available at* https://apps.dtic.mil/sti/trecms/pdf/AD1126470.pdf.

[546] M&M Staff, AI Impact Analysis on Hypersonic Weapons Industry, *Markets and Markets* (n.d.), *available at* https://www.marketsandmarkets.com/ResearchInsight/ai-impact-analysis-on-hypersonic-weapons-industry.asp#:~:text=AI-Enhanced%20Simulation%20and%20Testing,systems%20under%20rigorous%20military%20standards.

[547] M&M Staff, AI Impact Analysis on the Rocket and Missile Industry*,* *Markets and Markets* (n.d.), *available at* https://www.marketsandmarkets.com/ResearchInsight/ai-impact-analysis-rocket-missile-industry.asp#:~:text=AI%20also%20supports%20autonomous%20targeting,with%20aerospace%20engineering%20at%20scale.&text=This%20FREE%20sample%20includes%20market,See%20for%20yourself.

[548] *Id.*

[549] *Id.*

[550] *Id.*

[551] *Id.*

[552] M&M Staff, AI Impact Analysis on the Missile Seekers Industry, *Markets and Markets* (n.d.), *available at* https://www.marketsandmarkets.com/ResearchInsight/ai-impact-analysis-missile-seekers-industry.asp#:~:text=Artificial%20intelligence%20is%20profoundly%20reshaping,are%20also%20redefining%20sensor%20fusion.

not merely the use of AI, as advocated in Suggestion #9, but also the continuous quest for improvement, whether incrementally or disruptively.[553] For example, in active missile production, better missile warheads are an incremental technology, whereas hypersonic missiles are a disruptive technology. The key is to search for better weapons systems in general and better missile systems in particular.

Suggestion #11: Remove Unneeded Department of Defense Requirements

In missile production, the DOD imposes its requirements on primary missile manufacturers.[554] [555] These requirements fall under the DOD, not the manufacturers themselves. The DOD imposes stringent requirements on primary missile manufacturers that govern the entire manufacturing lifecycle from design and production to final testing and delivery.[556] These requirements are enforced through a system of regulatory compliance, financial oversight, and testing protocols managed by specialized DOD agencies.[557]

Removing the surge capacity for a given set of missiles is not only the responsibility of a primary missile manufacturer, but also the DOD. This is not to say that a given requirement is not critical when producing a missile. On the contrary, many requirements are essential and should be obeyed and implemented. The issue here is whether a specific requirement is needed. If so, then the requirement should likely remain. On the other hand, DOD requirements may be present that serve no other purpose but to impede production. Thus, DOD requirements regarding missile production should be reviewed and evaluated to determine their usefulness and whether they enhance the production process or the final product.

Suggestion #12: Reevaluate Just-in-Time Manufacturing Procedures

According to Banton, just-in-time (JIT) manufacturing is a “management strategy that aligns raw-material orders from suppliers directly with production schedules.”[558] Firms use this inventory strategy to increase efficiency and reduce waste by receiving goods as needed for the production process, thereby reducing inventory costs.[559] The JIT manufacturing process requires producers to forecast demand accurately.[560]

JIT inventory systems have some advantages over traditional inventory systems. Production runs are short, so manufacturers can easily move from one product to another. JIT reduces costs by minimizing warehouse needs.[561] Firms also spend less on raw materials because they purchase only the resources needed to make the products ordered.[562] The disadvantages of a JIT inventory system involve supply chain disruptions. If a supplier cannot deliver the goods promptly, this could affect the entire production line.[563] Regarding the surge capacity problem, a substantial increase in demand for active missiles would likely lead to a significant production delay.[564]

Suggestion #13: Reconsider Lean Manufacturing Procedures

As Daniel previously stated, lean manufacturing, also known as lean production or lean, is “a methodology that focuses on minimizing waste within manufacturing systems while simultaneously maximizing productivity.”[565] Waste is seen as anything that customers do not believe adds value to the final product, or are unwilling to pay for.[566] In terms of the surge capacity problem, waste could be construed as unused inventory. If a surge were to occur, that unused inventory could be used to relieve the production constraints it creates. For example, if excess inventory exists at a primary missile manufacturing facility and the President, along with the DOD, requires the manufacturer to produce, say, 1,000 additional specific missiles, the firm may be able to meet the demand because it has the necessary additional inventory. On the other hand, if the manufacturer strictly adheres to lean manufacturing

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[553] CLAYTON CHRISTIANSEN, THE INNOVATOR'S DILEMMA: THE REVOLUTIONARY BOOK THAT WILL CHANGE THE WAY YOU DO BUSINESS (Harper Business Publications Oct. 4, 2011).
[554] Heather Taylor, Top Rules for Government Contractors: Essential Knowledge for Compliance, *Select GCR* (Dec. 17, 2024), *available at* https://selectgcr.com/government-contracts/top-rules-for-government-contractors-essential-knowledge-for-compliance/#:~:text=In%20today's%20digital%20age%2C%20cybersecurity,Standards%20and%20Technology%20(NIST).
[555] DOD Staff, Defense-Manufacturing-Management-Guide-for-PMs, *U. S. Department of Defense* (n.d.), *available at* https://www.dau.edu/sites/default/files/Migrated/ToolAttachments/Defense-Manufacturing-Management-Guide-for-PMs.pdf.
[556] *Id.*
[557] *Id.*
[558] Caroline Banton, *supra*, note 425.
[559] *Id.*
[560] *Id.*
[561] *Id.*
[562] *Id.*
[563] *Id.*
[564] *Id.*
[565] Diann Daniel, *supra*, note 435.
[566] *Id.*

procedures, the company might be delayed in manufacturing the additional missiles. A primary missile manufacturer should maintain some excess inventory to meet additional missile demand if needed.

Suggestion #14: Promote Labor Force Training that Focuses on Simple Solutions

The idea behind this suggestion is to train the missile manufacturing workforce to focus on generating simple solutions to design and production problems. From a design standpoint, to avoid the surge capacity problem, missile designers should consider a missile as a whole and evaluate its components based on its complexity. From a hardware perspective, if there are a significant number of moving parts, the hardware design should be reviewed to determine if fewer parts can achieve the original design's objective.[567] [568] When there are too many moving parts, issues can include increased points of failure, unneeded complexity, inefficiency, a higher likelihood of errors, and the risk of knowledge loss.[569] The key is to keep a design simple, no matter how difficult this goal may be.

From a software viewpoint, the complexity of the programming should be critically evaluated. For example, if the software uses recursion, the recursive routines should be unwound to avoid excessive stack usage, which is invisible in C, C++, Java, and other higher-level languages.[570] Recursion can result in stack overflows, increased memory consumption, debugging complexity, difficulty in maintaining the source code, missing or incorrect base cases, and non-converging recursive steps.[571] [572]

Another software technique to avoid is inheritance. Although using inheritance can reduce programming time, the technique has a drawback: if the characteristics or properties of a parent, grandparent, or even great-grandparent are changed, inheritance of variables across generations can lead to unexpected results that are difficult to identify and even more difficult to correct.[573] The primary issues with inheritance in software are tight coupling, increased complexity, and rigid hierarchies that are hard to change.[574] Tight coupling occurs when changes to a parent class break all derived classes, leading to fragility.[575] The inherent rigidity of inheritance makes it strenuous to refactor or modify. Complex or deep hierarchies can be perplexing to manage.[576] Inherent rigidity frequently results in the "diamond problem," where, with multiple inheritance, ambiguity arises from a class inheriting from two classes with a common ancestor.[577] The result is that the production of an active missile can be significantly delayed due to two dubious software programming techniques.

Suggestion #15: Diminish Union Work Rules that Stifle Innovation

This is a suggestion that may have political overtones. Union work rules exist to provide workers a collective voice in negotiating for better wages, benefits, working conditions, and to ensure that workers are treated fairly and not terminated unjustly.[578] [579] [580]

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567 A.J. Rusli, Too Many Moving Parts!, *LinkedIn.com (*Apr. 7, 2019), *available at* https://www.linkedin.com/pulse/too-many-moving-parts-a-j-rusli-mbcs-citp/.

568 Eric P. Bloom, Beware of Too Many Moving Parts, *Metro West Daily News* (May 18, 2019), *available at* https://www.metrowestdailynews.com/story/business/2019/05/18/beware-too-many-moving-parts/5121333007/?gnt-cfr=1&gca-cat=p&gca-uir=true&gca-epti=z119603e004200v119603b0096xxd119665&gca-ft=195&gca-ds=sophi.

569 *Id.*

570 SC Staff, 13-3. Benefits and Drawbacks of Recursion, *School of Computing* (n.d.), *available at* https://comp.mga.edu/learning/python/module/13/topic/84#:~:text=Performance:%20Recursive%20functions%20can%20be,can%20lead%20to%20performance%20bottlenecks.

571 *Id.*

572 William Dale, Recursion: The Pros and Cons, *Medium* (May 9, 2018), *available at* https://medium.com/@williambdale/recursion-the-pros-and-cons-76d32d75973a.

573 Borislav Stoilov, Why You Should Think Twice Before Using Inheritance, *Medium* (Oct. 18, 2022), *available at* https://medium.com/@b.stoilov/why-you-should-think-twice-before-using-inheritance-573545dcd8e1.

574 *Id.*

575 *Id.*

576 *Id.*

577 *Id.*

578 *See generally*, Frankie Kourtis, 5 Labor Union Rules and Regulations Employers Should Know, *Labor Soft* (Nov. 2, 2023), *available at* https://www.laborsoft.com/blog/5-labor-union-rules-and-regulations-employers-should-know#:~:text=Employers%20may%20wish%20they%20didn,Safety%20practices.

579 DPE Staff, I'm a Professional. What Can a Union Do for Me?, *Department of Professional Employees* (n.d.), *available at* https://www.dpeaflcio.org/other-publications/im-a-professional-what-can-a-union-do-for-me#:~:text=What%20can%20a%20union%20offer%20me%20on,help%20with%20child%20care%20and%20elder%20care.

580 JML Staff, The Role of Unions in Modern Employment, *JML Law* (Jan. 31, 2025), *available at* https://jmllaw.com/the-role-of-unions-in-modern-employment.shtml#:~:text=The%20Importance%20of%20Unions%20in%20the%20Workplace,treatment%2C%20wrongful%20termination%2C%20and%20unsafe%20working%20conditions.

When bargaining as a group, employees can negotiate from a position of strength rather than weakness for fair working hours, overtime pay, safety measures, and job training.[581]

When the surge capacity problem is introduced into the manufacturing of active missiles, the union work rules, no matter how reasonable they may be, can impede production.[582] When a surge in missile demand occurs, union work rules can act as friction, slowing down the manufacturing process. This friction can come from rigid job classification, a seniority-based system, a lack of meritocracy, limited flexibility, resistance to performance-based evaluations, abuse of power by labor leaders, inequality among workers, and resistance to change.[583] For primary missile manufacturers, the result can be a failure to meet the demand for active missiles when the federal government needs them. The consequences can be militarily detrimental when a kinetic conflict occurs. In other words, the existence of unneeded or inhibiting union work rules can spell the difference between definitive victory, a stalemate, or even a loss. Union work rules may warrant evaluation to determine their effect during a surge. Every effort should be made to ensure that inflexible union work rules do not jeopardize national security. In the modern multi-polar world, union work rules may be examined to ensure they do not impede the responsiveness of defense manufacturing under surge conditions.

Suggestion #16: Mechanisms for Enhancing the United States' Missile Surge Capacity

The United States maintains a suite of legal and contractual instruments designed to expand missile production capacity without invoking martial law or emergency powers. These mechanisms, rooted in statutory authorities, enable the DOD and Congress to require, incentivize, or fund industrial readiness during peacetime. Among the most potent tools is the Defense Production Act (DPA), which grants the President authority to prioritize missile-related contracts, allocate critical materials, and expand production infrastructure. Title III of the DPA further authorizes investment in propulsion systems, guidance technologies, and rare-earth processing facilities essential to missile manufacturing.[584]

The Warstopper Program, administered by the Defense Logistics Agency (DLA), exemplifies preemptive surge investment. It funds idle or low-rate production lines for critical components, such as nerve agent antidotes and missile subsystems, ensuring rapid activation during crises.[585] Option contracts, authorized by Congress and executed by the DoD, function as industrial insurance: the government pays premiums for the right to surge production later, avoiding wasteful stockpiling.[586] [587] The National Defense Industrial Strategy (NDIS), a joint executive-legislative initiative, aligns workforce development, supply chain resilience, and acquisition reform to support long-term missile readiness.[588] Emergency appropriations inject capital into production lines without invoking emergency powers, offering fiscal agility during geopolitical escalations.[589] These instruments collectively demonstrate that martial law is not a prerequisite for industrial mobilization. Instead, they leverage legal frameworks to maintain warm production lines, pre-position tooling, and ensure surge elasticity.

Suggestion #17: The People's Republic of China's Centralized Surge Model

China's missile production system diverges sharply from the United States model. It is centralized, vertically integrated, and state-controlled.[590] Entities such as the China Aerospace Science and Technology Corporation (CASTC) and China Aerospace Science and Industry Corporation (CASIC) operate under military oversight, with built-in surge capacity and modular factory designs. The

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[581] *Id.*

[582] MBUSI Staff, Union Work Rules Are Unnecessary, *Mercedes-Benz US International* (Mar. 4, 2024), *available at* https://mbusiworkersinfo.com/update/union-work-rules-are-unnecessary/#:~:text=Strict%20union%20rules%20may%20limit,competitive%20in%20a%20dynamic%20market.&text=Some%20union%20rules%20may%20resist,not%20adequately%20recognized%20or%20rewarded.&text=The%20concentration%20of%20power%20in,union%20resources%20for%20personal%20gain.&text=Segregation%20resulting%20from%20union%20rules,impacting%20the%20overall%20work%20environment.

[583] *Id.*

[584] OASD-IBP Staff, DPA Title III Overview, *U.S. Department of Defense* (2025), *available at* https://www.businessdefense.gov/ibr/mceip/dpai/dpat3/docs/DPA-TitleIII-Overview.pdf.

[585] Beth Reese, Warstopper Program Changes Could Improve Surge Capabilities for Critical Supplies, *Defense Logistics Agency* (Apr. 18, 2025), *available at* https://www.dla.mil/About-DLA/News/News-Article-View/Article/4157222.

[586] GAO Staff, Warstopper Program: Comprehensive Cost Estimate Needed to Evaluate Potential Expanded Access to Emergency Medications, *U.S. Government Accounting Office* (Jul. 29, 2024), *available at* https://www.gao.gov/products/gao-24-106109.

[587] Ronald O'Rourke, Multiyear Procurement (MYP) and Block Buy Contracting in Defense Acquisition: Background and Issues for Congress, *Congressional Research Service* (Sep. 12, 2022), *available at* https://www.congress.gov/crs-product/R41909.

[588] DOD Staff, National Defense Industrial Strategy, *U.S. Department of Defense* (Nov. 16, 2023), *available at* https://www.businessdefense.gov/docs/ndis/2023-NDIS.pdf.

[589] Gene Healy, CATO Handbook for Policymakers, *CATO Institute* (2022), *available at* https://www.cato.org/sites/cato.org/files/2022-12/cato-handbook-9th-edition-09.pdf.

[590] Marcus Schiller, The Great Leap? China's Ballistic Missile Program, *Institute for Peace Research and Security Policy at the University of Hamburg* (May 2024), *available at* https://www.ifsh.de/file/publication/Research_Report/013/Research_Report_013-24_EN_V2_web.pdf.

People's Liberation Army Rocket Force (PLARF) benefits from prioritized access to raw materials, labor, and logistics, enabling rapid scaling of missile output.[591]

China's strategic infrastructure is dual-use by design, allowing civilian sectors, particularly electronics and aerospace, to be militarized swiftly. Rare-earth dominance further enhances surge potential: China refines over 80% of the global rare earth supply, including dysprosium and yttrium, which are critical for missile guidance and heat-resistant components.[592] Export restrictions on these minerals serve both economic and strategic ends.[593] [594] To close this gap, analysts recommend expanding Warstopper-like mechanisms into missile production, including funding idle lines, pre-positioning rare earths, and deploying Title III DPA investments for modular infrastructure.[595]

Suggestion #18: Replacing Complex Missiles with Scalable Designs

Modern missile warfare increasingly favors quantity over complexity. Advanced systems, such as the United States' Tomahawk or the Russian Iskander, are expensive and time-consuming to produce, whereas simpler designs, such as Ukraine's Sapsan ballistic missile or the United States' Extended Range Attack Munition (ERAM), offer rapid scalability and cost-effectiveness.[596] Simpler missiles reduce dependency on fragile supply chains and rare materials, enabling faster replenishment during wartime. A $100,000 missile that disables a $10 million radar exemplifies strategic efficiency. Ukraine's pivot to domestic production of missiles reflects that it is more economical to build locally than to await Western aid.[597]

Operational saturation is another advantage. Massed missile attacks can overwhelm air defenses, which is a tactic Russia has employed repeatedly. Ukraine's serial production of the Sap San system aims to penetrate Russian defenses with precision.[598] In response, the United States Air Force is developing ERAMs, modular, GPS-resilient munitions compatible with existing aircraft, tailored to the attritional nature of the Ukraine-Russia conflict.[599] Russia's reliance on domestically produced systems like the Kh-22 and Shahed drones underscores the strategic value of scalable, low-cost munitions.[600]

Suggestion #19: Adopt the German Empire's Defense Industry Model

The German Empire (1871–1918) operated a defense industry characterized by centralized control and militarized industrial policy. Kaiser and General Staff influenced procurement and strategic priorities, forging symbiotic relationships with firms such as Krupp and Mauser.[601] These companies functioned as quasi-state entities, producing artillery, rifles, and naval armaments under government contracts. Civilian oversight was minimal; military elites dominated decision-making. During World War I, the government transitioned to a war economy, imposing tighter controls, rationing resources, and focusing labor towards arms production.[602] Innovation and production were subordinated to military doctrine, reflecting a hierarchical relationship between state

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591 Peter Wood, & Alex Stone, China's Ballistic Missile Industry, *China Aerospace Studies Institute* (Nov. 4, 2021), *available at* https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/PLARF/2021-05-11%20Ballistic%20Missile%20Industry.pdf.

592 NMIC Staff, Rare Earths Statistics and Information, *National Minerals Information Center* (2025), *available at* https://www.usgs.gov/centers/national-minerals-information-center/rare-earths-statistics-and-information.

593 CLT Staff, Export Control Law of the People's Republic of China, *China Law Translate* (Oct. 19, 2020), *available at* https://www.chinalawtranslate.com/en/export-control/#_Toc54004247.

594 Gracelin Baskaran, China's New Rare Earth and Magnet Restrictions Threaten U.S Defense Supply Chains, *Center For Strategic & International Studies* (Oct. 9, 2025), *available at* https://www.csis.org/analysis/chinas-new-rare-earth-and-magnet-restrictions-threaten-us-defense-supply-chains.

595 OASD-IBP Staff, *supra*, note 584.

596 Parth Satam, US Developing Cheap, Mass-Producible ERAMs for Ukraine: Here's Why, *The Aviationist* (Jul. 15, 2024), *available at* https://theaviationist.com/2024/07/15/us-developing-cheap-mass-producible-erams-for-ukraine-heres-why/.

597 Yuri Lapaiev, Ukraine Ramps Up Defense Production With Increased International Cooperation, *Eurasia Daily Monitor* (Sep. 17, 2025), *available at* https://jamestown.org/program/ukraine-ramps-up-defense-production-with-increased-international-cooperation/#:~:text=According%20to%20the%20Ministry%20of,see%20EDM%2C%20July%208).

598 Defense.info Analysis Team, Ukraine's SAPSAN Missile, *Defense.info* (Jun. 22, 2025), *available at* https://defense.info/defense-systems/ukraines-sapsan-missile/#:~:text=The%20SAPSAN%20provides%20Ukraine%20with,against%20hardened%20targets%20and%20infrastructure.

599 Joseph Trevithick, Air Force's Cheap and Fast to Produce Long-Range Missile Is Being Built For Ukraine, *The War Zone* (Jul. 11, 2024), *available at* https://www.twz.com/air/air-forces-cheap-and-fast-to-produce-long-range-missile-is-being-built-for-ukraine#:~:text=The%20new%20revelation%20that%20the,beyond%20the%20conflict%20in%20Ukraine.

600 Michelle Grisé, Mark Cozad, Anna M. Dowd, Mark Hvizda, John Kennedy, Marta Kepe, Clara de Lataillade, Krystyna Marcinek, & David Woodworth, Russia's Military After Ukraine: Potential Pathways for the Postwar Reconstitution of the Russian Armed Forces, *RAND Corp.* (Jan. 16, 2025), *available at* https://www.rand.org/content/dam/rand/pubs/research_reports/RRA2700/RRA2713-1/RAND_RRA2713-1.pdf.

601 VOLKER ROTH BERGHAHN, GERMANY AND THE APPROACH OF WAR IN 1914 (St. Martin's Press 1973).

602 GERALD D. FELDMAN, ARMY, INDUSTRY, AND LABOR IN GERMANY, 1914–1918 (Princeton University Press 1966).

and industry. This model contrasts sharply with the decentralized, contract-driven United States defense ecosystem, where private firms operate independently but rely heavily on federal procurement and strategic guidance.

Suggestion #20: Adopt the United States' Warstopper Program and Strategic Elasticity

The Warstopper Program, administered by the Defense Logistics Agency (DLA), represents a contractual approach to industrial surge readiness. Rather than relying on centralized mandates or wartime mobilization, Warstopper leverages preemptive investment to preserve latent production capacity for critical defense items. This includes low-rate or idle manufacturing lines for components such as nerve agent antidotes, missile subsystems, and other surge-critical assets that are not economically viable for continuous production.[603]

Key features of the program include surge contracts that compensate the industry for maintaining tooling, workforce, and supply chains in a state of readiness.[604] Option clauses embedded in these contracts allow the Department of Defense (DoD) to rapidly activate production without resorting to peacetime stockpiling, thereby avoiding logistical waste and budgetary inefficiency.[605] Selective funding targets items deemed essential for crisis response but unlikely to attract sustained commercial investment. Unlike China's vertically integrated, state-controlled defense economy, the Warstopper model is incentive-driven and decentralized. It functions as a hedge against industrial atrophy, preserving elasticity in the defense supply chain without imposing command-style directives.[606]

SUGGESTIONS SELECTED TO RESOLVE THE SURGE CAPACITY PROBLEM

This section has two subsections. Among the Suggestions above, the selected solutions are listed. The second subsection explains why the solutions presented in the first subsection were chosen. Each subsection is discussed in turn.

Suggestions Selected

The selected suggestions are categorized as highly likely, moderately likely, neutrally likely, moderately unlikely, or highly unlikely. In assessing and ranking 20 proposed suggestions for mitigating missile surge capacity shortfalls, a 5-point Likert-like scale was used, with scores based on feasibility, legal viability, industrial precedent, and alignment with strategic objectives. The suggestions in each subsection are ranked by their likelihood of mitigating the surge capacity problem. In some cases, several suggestions may have an equal likelihood of success. Each of the five subsections is discussed in turn.

Highly Likely Suggestions Selected

Of the 20 suggestions listed in the previous section, two were assessed as highly likely to help address the surge capacity problem. The suggestions are Suggestion #14: Promote Labor Force Training that Focuses on Simple Solutions, and Suggestion #20: Adopt the United States' Warstopper Program and Strategic Elasticity. Table 21 lists the two suggestions and states the case study's findings.

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[603] Beth Reese, *supra*, note 585.

[604] DOD Staff, The National Defense Industrial Strategy (NDIS): Enabling a Modernized Defense Industrial Ecosystem, *U.S. Department of Defense* (n.d.), *available at* https://www.businessdefense.gov/NDIS.html.

[605] Michael Hogan, The US Needs a Stronger Defense Industrial Base. Option Contracts Can Help., *Atlantic Council* (Oct. 28, 2024), *available at* https://www.atlanticcouncil.org/blogs/new-atlanticist/the-us-needs-a-stronger-defense-industrial-base-option-contracts-can-help/.

[606] Beth Reese, *supra*, note 585.

Surge Capacity Issues for Selected United States Active Missiles

Table 21: Highly Likely Suggestions Selected

Suggestion	Feasibility	Legal Viability	Industrial Precedent	Strategic Alignment	Likelihood
Suggestion #14: Promote Labor Force Training that Focuses on Simple Solutions	High	Strong	Strong (WWII, DPAI)	Strong (NDIS, surge goals)	Highly Likely
Suggestion #20: Adopt the United States' Warstopper Program and Strategic Elasticity	High	Strong	Strong (DLA success)	Strong (DOD embedded)	Highly Likely

These two suggestions were selected as highly likely because of their relative ease of implementation. They were highly feasible, legally quite viable, had strong industrial precedent, and were closely aligned with the military's strategic goals.

Moderately Likely Suggestions Selected

This subsection presents four moderately likely suggestions that may help address the surge capacity problem. These suggestions are Suggestion #7: Convert Existing Manufacturing Facilities, Suggestion #12: Reevaluate Just-in-Time Manufacturing Procedures, Suggestion #18: Replacing Complex Missiles with Scalable Designs, and Suggestion #3: Significantly Increase Competition. Table 22 records the four suggestions and describes this study's discoveries.

Table 22. Moderately Likely Suggestions Selected

Suggestion	Feasibility	Legal Viability	Industrial Precedent	Strategic Alignment	Likelihood
Suggestion #7: Convert Existing Manufacturing Facilities	Moderate	Permissible	Strong (DPAI, WWII)	Strong (capacity expansion)	Moderately Likely
Suggestion #12: Reevaluate Just-in-Time Manufacturing Procedures	Moderate	Permissible	Mixed (limited in defense)	Strong (post-Ukraine shift)	Moderately Likely
Suggestion #18: Replacing Complex Missiles with Scalable Designs	Moderate	Flexible	Strong (dual-use models)	Strong (NDIS-aligned)	Moderately Likely
Suggestion #3: Significantly Increase Competition	Moderate	Encouraged	Strong (SBIR, DIU)	Strong (DOD priority)	Moderately Likely

The four suggestions were deemed moderately likely because their feasibility, legal viability, industrial precedent, and strategic alignment were not as robust as those of their counterparts in Table 21. Even so, the four characteristics were generally favorable, demonstrating that if implemented, these four suggestions will likely be successful in resolving the surge capacity problem.

Neutrally Likely Suggestions Selected

In this subsection, five suggestions were classified as neutrally likely. In other words, the viability of these suggestions indicates they have limited potential to address the surge capacity problem. They are Suggestion #8: Increase Innovation by Using Simplified Technologies, Suggestion #6: Expedite Expansion of Physical Facilities, Suggestion #10: Promote Disruptive Engineering Technologies, Suggestion #16: Mechanisms for Enhancing the United States' Missile Surge Capacity, and Suggestion #13: Reconsider Lean Manufacturing Procedures. Table 23 enumerates the five neutrally likely suggestions.

Table 23. Neutrally Likely Suggestions Selected

Suggestion	Feasibility	Legal Viability	Industrial Precedent	Strategic Alignment	Likelihood
Suggestion #8: Increase Innovation by Using Simplified Technologies	Mixed	Permissible	Mixed (AM trials)	Mixed (not mainstream)	Neutrally Likely
Suggestion #6: Expedite Expansion of Physical Facilities	Long Lead	Permissible	Strong (DOD investments)	Mixed (delayed impact)	Neutrally Likely
Suggestion #10: Promote Disruptive Engineering Technologies	Scaling Issues	Permissible	Mixed (startups)	Mixed (cultural resistance)	Neutrally Likely
Suggestion #16: Mechanisms for Enhancing the United States' Missile Surge Capacity	Conceptual	Permissible	Mixed (AAF reforms)	Mixed (bureaucratic inertia)	Neutrally Likely
Suggestion #13: Reconsider Lean Manufacturing Procedures	Mixed Results	Permissible	Mixed (debated in defense)	Mixed (under reassessment)	Neutrally Likely

If these five suggestions were implemented, the results would likely be mixed, with long lead times, scaling issues, and conceptual issues. Legally, the five suggestions would be permissible, but for the most part, the industrial precedent and the strategic alignment would be mixed.

Moderately Unlikely Suggestions Selected

Two moderately unlikely suggestions were identified. They were Suggestion #9: Reduce Unneeded Missile Complexity and Suggestion #4: Reduce Excessive City Ordinances, State Laws, and Regulations. They are Suggestion #9: Reduce Unneeded Missile Complexity and Suggestion #4: Reduce Excessive City Ordinances, State Laws, and Regulations. Table 24 presents the reasons why the study found the suggestions to be moderately unlikely.

Table 24. Moderately Unlikely Suggestions Selected

Suggestion	Feasibility	Legal Viability	Industrial Precedent	Strategic Alignment	Likelihood
Suggestion #9: Reduce Unneeded Missile Complexity	Risky	Permissible	Low (performance tradeoffs)	Low (capability degradation)	Moderately Unlikely
Suggestion #4: Reduce Excessive City Ordinances, State Laws, and Regulations	Minimal Impact	Permissible	Low (most laws are federal)	Low (limited strategic value)	Moderately Unlikely

Suggestion #9, which proposes reducing unneeded missile complexity, and Suggestion #4, which recommends reducing excessive city ordinances and state laws. The two suggestions are legally permissible but have limited effectiveness and pose potential implementation challenges, with minimal impact, particularly when performance trade-offs and strategic alignment are low.

Highly Unlikely Suggestions Selected

The study identified seven highly unlikely suggestions. They are Suggestion #11: Remove Unneeded Department of Defense Requirements, Suggestion #15: Diminish Union Work Rules that Stifle Innovation, Suggestion #17: The People's Republic of

China's Centralized Surge Model, Suggestion #19: Adopt the German Empire's Defense Industry Model, Suggestion #5: Decrease Federal Laws, Regulations, and International Treaties, Suggestion #2: The President Declares Martial Law, and Suggestion #1: Do Nothing. Table 25 displays these suggestions.

Table 25. Highly Unlikely Suggestions Selected

Suggestion	Feasibility	Legal Viability	Industrial Precedent	Strategic Alignment	Likelihood
Suggestion #11: Remove Unnecessary Department of Defense Requirements	Infeasible	Violates Law	None	Incompatible	Highly Unlikely
Suggestion #15: Diminish Union Work Rules that Stifle Innovation	Politically Toxic	Violates Labor Law	None	Incompatible	Highly Unlikely
Suggestion #17: The People's Republic of China's Centralized Surge Model	Incompatible	Violates Norms	None	Opposes U.S. Values	Highly Unlikely
Suggestion #19: Adopt the German Empire's Defense Industry Model	Misaligned	Legally Unclear	Mixed (ESG focus)	Not Scalable	Highly Unlikely
Suggestion #5: Decrease Federal Laws, Regulations, and International Treaties	Infeasible	Requires Legislation	None	Undermines Oversight	Highly Unlikely
Suggestion #2: The President Declares Martial Law	Legally Constrained	Constitutionally Limited	None	Politically Destabilizing	Highly Unlikely
Suggestion #1: Do Nothing	Neglectful	Permissible	None	Fails Strategic Goals	Highly Unlikely

These seven suggestions face significant feasibility, legal, and strategic challenges and are generally considered impractical within current policy and governance frameworks. Their legal viability ranges from currently illegal to constitutionally limited to permissible. For the majority of the highly unlikely suggestions, there is no industrial precedent. Finally, from the perspective of strategic alignment, the suggestions are incompatible, oppose the United States' values, not scalable, undermine oversight, politically destabilizing, or fail to promote strategic goals.

Justification of the Suggestions Selected

The desire to revitalize the United States' defense industrial base (DIB) for surge readiness has gained renewed urgency amid recent geopolitical tensions and the logistical lessons of the COVID-19 pandemic. A range of policy interventions were proposed to enhance surge capacity, each varying in feasibility, political viability, and alignment with existing DOD frameworks. The justifications for the selected suggestions employ the same organizational structure as the subsection on the selected suggestions. The justifications are organized as highly likely, moderately likely, neutrally likely, moderately unlikely, and highly unlikely. As previously stated, the suggestions in each subsection are ranked and discussed based on their likelihood to mitigate the surge capacity problem. In some instances, several suggestions may have an equal likelihood of being successful. If so, the suggestions are discussed in numerical order. Each of the five subsections is discussed in turn.

Justification for the Highly Likely Suggestions

Suggestions rated as highly likely have strong institutional support, existing infrastructure, and precise alignment with current DOD priorities. These include workforce training for simplified tasks by expanding the Warstopper program.[607] Both are already embedded in federal policy and budgetary planning, making them immediately actionable. Workforce development is typically bipartisan and scalable through existing programs, such as SkillBridge and Manufacturing Institutes, and is endorsed by existing legislation.[608] The Warstopper program, meanwhile, has a proven track record of maintaining surge-ready capacity for critical components. These proposals require minimal legislative change and are reinforced by recent lessons from Ukraine and Indo-Pacific deterrence planning.

Investing in workforce training to simplify production processes is a proven way to increase throughput and resilience. Historical mobilizations, such as World War II, and modern workforce development strategies emphasize the importance of scalable, modular training for surge readiness.[609] [610] The DLA's Warstopper Program has demonstrated its effectiveness in preserving surge capacity for critical items such as N95 masks and nerve agent antidotes. It enables low-cost readiness without stockpiling, using flexible contracts and demand aggregation.[611]

Similarly, revitalizing the Warstopper Program, originally developed under the Defense Production Act, to maintain warm production bases for critical items, requiring them to receive a rating of 5. The program already possesses institutional infrastructure and funding mechanisms, making it a low-friction, high-impact option for bolstering surge readiness.[612] This RAND study demonstrates how the Ukraine conflict exposed shortfalls in surge capacity and underscored the need for scalable, preemptive industrial-readiness strategies, such as Warstopper and workforce development.[613]

Justification for the Moderately Likely Suggestions

The moderately likely suggestions are technically feasible and politically palatable but require moderate coordination, funding, or cultural shifts. Examples include converting existing facilities, reevaluating just-in-time logistics, and promoting hybrid surge mechanisms. These strategies build on existing models and reflect growing awareness of supply chain vulnerabilities. However, they may face bureaucratic inertia, interagency friction, or uneven adoption across services. Suggestion #3 also falls into this category because it is supported by acquisition reform but constrained by the limited pool of qualified vendors. These proposals are realistic but depend on sustained leadership and targeted investment to reach full implementation.

Suggestion #12 proposes converting existing facilities, reevaluating JIT logistics, implementing hybrid surge mechanisms, and increasing competition. Repurposing commercial or underutilized defense facilities is a feasible and cost-effective strategy. Recent DPAI investments have successfully expanded domestic production of critical components, such as semiconductors and advanced packaging.[614] The DOD has acknowledged that JIT logistics models fail under high-end conflict conditions. The Ukraine war exposed the vulnerabilities[615] in munitions supply chains, prompting a shift toward predictive logistics and stockpiling.[616]

Suggestion #18 could involve combining organic and commercial capacity through flexible contracting and risk-based trade-space decisions, a model increasingly seen as viable for scalable surge.[617] The DOD has identified industrial consolidation as a key risk. Increasing competition through small business engagement and flexible acquisition pathways is a core pillar of the

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607 DOC Staff, Programs, U.S. Department of Commerce (n.d.), *available at* https://www.manufacturing.gov/programs.

608 DOD Staff, What Is SkillBridge? U.S. Department of Defense (Sep. 5, 2025), *available at* https://skillbridge.osd.mil/program-overview.htm.

609 Paul W. Rhode, James M. Snyder, Jr., & Koleman Strumpf, The Arsenal of Democracy: Production and Politics during WWII, 166 JOURNAL OF PUBLIC ECONOMICS, 145-161 (Oct. 2018), *available at* https://www.sciencedirect.com/science/article/abs/pii/S0047272718301543.

610 Robert J. Thomas, Training for War Production: Lessons from the Arsenal of Democracy, 45 INDUSTRIAL & LABOR RELATIONS REVIEW, 123 (Oct. 1991).

611 Beth Reese, *supra*, note 585

612 Wanda A. Scott et al., Defense Logistics Agency's Warstopper Program, *Defense Technical Information Center* (Aug. 15, 2007), *available at* https://apps.dtic.mil/sti/tr/pdf/ADA472192.pdf.

613 *Id.*

614 Robert Greenway et al., A Strategy to Revitalize the Defense Industrial Base for the 21st Century, *The Heritage Foundation* (Apr. 7, 2025), *available at* https://www.heritage.org/defense/report/strategy-revitalize-the-defense-industrial-base-the-21st-century.

615 Alisa Laufer, Howard J. Shatz & Omar Danaf, Implications of Russia's War on Ukraine for the U.S. and Allied Defense Industrial Bases, *RAND Corp.* (May 22, 2025), *available at* https://www.rand.org/pubs/research_reports/RRA3141-3.html.

616 David Vergun, Official Says Just-In-Time Deliveries Fail in High-End Competition, *U.S. Department of Defense* (Mar. 16, 2023), *available at* https://www.war.gov/News/News-Stories/Article/Article/3331657/.

617 ASB Staff, *supra*, note 475.

NDIS.[618]

Suggestion #7**,** which proposes to convert existing facilities, such as mothballed military installations or underutilized industrial sites, is another promising avenue. This strategy avoids the delays and costs associated with greenfield construction and can be implemented with moderate investment and interagency coordination. It is moderately feasible, but contingent on overcoming local zoning and environmental permitting hurdles.

Justification for the Neutrally Likely Suggestions

Suggestions rated neutrally likely are conceptually sound but face significant operational or cultural barriers. Simplified technologies, disruptive engineering, and strategic simplicity offer potential efficiency gains, but challenge entrenched defense norms. For instance, simplification may reduce production time but risks compromising capability and interoperability. Expanding facilities is politically attractive but slow and capital-intensive. Reconsidering lean manufacturing practices is feasible, but deeply embedded in defense production culture. These strategies are neither impractical nor guaranteed. They require deliberate experimentation, pilot programs, and doctrinal flexibility to show their value.

Simplifying technologies by implementing Suggestion #8 is significant and could happen. Additive manufacturing and modular design offer promise but face adoption barriers, including qualification standards, workforce training, and capital investment.[619] Suggestion #6, which proposes expanding facilities, may begin but results in long lead times and permits delays, as workforce shortages limit near-term feasibility.[620] Another neutral option is Suggestion #10 that recommends promoting disruptive engineering. Nontraditional entrants, such as Anduril or Shield AI, are reshaping defense innovation, but scaling remains challenging due to cultural, regulatory, and funding barriers.[621] Efforts to streamline acquisition via the Adaptive Acquisition Framework (AAF) are underway, but bureaucratic inertia and risk aversion persist.[622] The lean principles highlighted in Suggestion #13 can improve efficiency but may undermine resilience in complex logistics environments. The DOD is currently reassessing the role of lean in light of recent conflicts.[623]

Furthermore, simplifying technologies to accelerate production is feasible, but there are risks of degrading capability and interoperability. Expanding physical facilities, as expressed in Suggestion #6, while politically attractive, is capital-intensive and slow to implement. Promoting disruptive engineering through agencies such as DARPA and the Defense Innovation Unit (DIU) is conceptually sound, but it faces bureaucratic resistance and slow adoption cycles. Strategic simplicity, focusing on fewer, more scalable systems, likewise garners a neutral rating due to the difficulty of enforcing standardization across services with divergent operational requirements. Reconsidering lean manufacturing principles is also likely, though neutrally so. Although lean remains entrenched in defense logistics culture, recent conflicts have prompted some flexibility. However, a complete paradigm shift remains unlikely without top-down mandates.

Justification for the Moderately Unlikely Suggestions

The moderately unlikely suggestions face structural resistance or legal complications, making implementation difficult. Reducing unneeded missile complexity, as advocated by Suggestion #9, may seem efficient on paper, but it may conflict with operational diversity and federalism. Services resist standardization due to mission-specific requirements. Local zoning and labor laws are outside federal control. These ideas may offer marginal gains but are unlikely to be adopted on a scale without major policy overhauls. Institutional inertia, legal boundaries, and the decentralized nature of United States governance constrain their feasibility. Similarly, as advised by Suggestion #4, reducing local regulations would require federal preemption of zoning and environmental laws, and such preemption is likely to encounter legal and political opposition.

[618] DOD Staff, State of Competition Within the Defense Industrial Base, *U.S. Department of Defense* (Feb. 2022), *available at* https://media.defense.gov/2022/feb/15/2002939087/-1/-1/1/state-of-competition-within-the-defense-industrial-base.pdf.

[619] Larry R. Holmes Jr., Additive Technology Revolutionizes Defense Manufacturing, *National Defense* (July 6, 2023), *available at* https://www.nationaldefensemagazine.org/articles/2023/7/6/additive-technology-revolutionizes-defense-manufacturing.

[620] DOD Staff, Department of Defense Awards $253.7 Million to Expand Facilities for Gas Turbine Engine Production, *U.S. Department of Defense* (Dec. 23, 2024), *available at* https://www.war.gov/News/Releases/Release/Article/4015691/.

[621] Jesse Klempner et al., A Rising Wave of Tech Disruptors: The Future of Defense Innovation, *McKinsey & Company* (Feb. 22, 2024), *available at* https://www.mckinsey.com/industries/aerospace-and-defense/.

[622] Donald J. Trump, Executive Order 14265: Modernizing Defense Acquisitions and Spurring Innovation, *The White House* (Apr. 9, 2025), *available at* https://www.whitehouse.gov/presidential-actions/2025/04/modernizing-defense-acquisitions-and-spurring-innovation-in-the-defense-industrial-base/.

[623] James Luck, Maximizing Efficiency: Why Defense Contractors Should Embrace Lean Manufacturing Principles, Odyssey (May 22, 2023), *available at* https://odysseydcs.com/maximizing-efficiency-why-defense-contractors-should-embrace-lean-manufacturing-principles/.

Reducing missile complexity is unlikely, as missile systems are inherently complex due to the performance and survivability requirements they must meet. Simplification risks degrading capability and interoperability.[624] Additionally, reducing local regulations will not replace reforming them. While regulatory reform is needed, it should be remembered that environmental constraints are federally mandated. Local deregulation alone offers a limited impact.[625]

Justification for the Highly Unlikely Suggestions

At the bottom of the feasibility spectrum are proposals such as removing DOD requirements, diminishing union rules, or adopting authoritarian industrial models like those of the People's Republic of China or the German Empire. These suggestions are either legally indefensible, politically toxic, or incompatible with United States governance norms. Declaring martial law to enforce industrial policy would violate constitutional protections and provoke widespread resistance. Finally, the option of inaction, or doing nothing, contradicts DOD assessments and leaves the nation vulnerable to surge failure in a peer conflict. Eliminating requirements would undermine acquisition discipline and violate statutory mandates.

Therefore, reform, not removal, is the path forward.[626] Union protections are legally entrenched and politically sensitive. Undermining them, as proposed in Suggestion #15, would provoke legal and workforce backlash.[627] China's defense model, as advocated in Suggestion #17, relies on state control, forced technology transfer, and opaque practices incompatible with United States law and values.[628] Adopting the German Empire's military-industrial complex strategy, as recommended in Suggestion #19, emphasizes long-term investment and environmental, social, and governance (ESG) reform but does not apply to the United States due to structural and cultural differences.[629] Although Suggestion #5 advises reducing federal laws or treaties that underpin industrial base resilience, doing so would increase risk and reduce oversight.[630] Declaring martial law, as put forward by Suggestion #2, is not feasible because martial law is legally constrained and historically disfavored. It cannot be used to require industrial production under the current law.[631] Doing nothing, as stated in Suggestion #1, would exacerbate readiness gaps. The DIB is already under strain and unable to meet surge demands.[632] These ideas are not only impractical but also destabilize the very foundations of the United States' defense policy and governance, rendering them non-starters in any serious planning context.

Justification Summary and Conclusion

The most viable surge mitigation strategies are those that build on existing programs, align with current policy frameworks, and offer scalable and politically feasible solutions. These include labor training, Warstopper revitalization, facility conversion, and various hybrid surge mechanisms. Conversely, proposals that undermine legal norms or require sweeping structural overhauls are unlikely to gain traction and may erode institutional legitimacy.

These 20 suggestions were outlined to mitigate surge capacity issues with the United States' missile programs. Analysts anticipate the possibility of high-intensity conflict or strategic disruption. The problem with the United States' strategy is that it is based on deterrence, not war.[633] In a blue-water war, losses will be inevitable. Those losses will need to be replaced in days and

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[624] Jerry R. Krill, Systems Engineering of Air and Missile Defenses, 22 JOHN HOPKINS APPLIED TECHNICAL DIGEST 3 (2001), *available at* https://secwww.jhuapl.edu/techdigest/Content/techdigest/pdf/V22-N03/22-03-Krill.pdf.
[625] Robert Greenway et al., *supra*, note 614.
[626] Pete Modigliani, Dan Ward, Tyler Lewis, Wayne McGee, Modernizing DoD Requirements: Enabling Speed, Agility, and Innovation, *Mitre Center for Technology and National Security* (Mar. 2020), *available at* https://www.mitre.org/sites/default/files/2021-11/prs-19-03715-2-modernizing-dod-requirements-enabling-speed-agility-and-innovation.pdf.
[627] AFL-CIO Staff, Resolution 31: Preserving Middle-Class Jobs, *AFL-CIO* (Jun. 12, 2022), *available at* https://aflcio.org/resolutions/resolution31.
[628] John Moolenaar (chairperson), Critical Minerals Policy Working Group Final Report: Creating Resilient Critical Mineral Supply Chains, *The Select Committee on the Strategic Competition Between the United States and the Chinese Communist Party* (2025), *available at* https://selectcommitteeontheccp.house.gov/sites/evo-subsites/selectcommitteeontheccp.house.gov/files/evo-media-document/Critical%20Minerals%20Report%20Cover%20%281%29-merged.pdf.
[629] Linus Terhorst, Lessons on Boosting Production from the German Defence-Industrial Strategy, *Royal United Services Institute* (Feb. 25, 2025), *available at* https://www.rusi.org/explore-our-research/publications/commentary/lessons-boosting-production-german-defence-industrial-strategy.
[630] Luke A. Nicastro, The U.S. Defense Industrial Base: Background and Issues for Congress, Congressional Research Service (Sep. 23, 2024), *available at* https://www.congress.gov/crs-product/R47751.
[631] Legal Clarity Team, Can the President Declare Martial Law?, *Legal Clarity* (Jul. 10, 2025), *available at* https://legalclarity.org/can-the-president-declare-martial-law/.
[632] Sandra R. Thomas, Viewpoint: Defense Industrial Base Sector Won't Surge Without Policy Changes, *National Defense* (Apr. 7, 2025), *available at* https://www.nationaldefensemagazine.org/articles/2025/4/7/.
[633] Ionut C. Popescu, Adapting US Defense Strategy to Great-Power Competition, 55 UNITED STATES ARMY WAR COLLEGE QUARTERLY PARAMETERS 1 (2025), *available at* https://press.armywarcollege.edu/parameters/vol55/iss1/7/.

weeks, not years.[634] While the Pentagon has rhetorically embraced great-power competition, its force structure, posture, and budgeting remain anchored in legacy deterrence models. Without aligning strategic planning to wartime realities, especially a potential war with China, the United States risks a possible crisis that could be avoided.

The United States' defense industrial base should likely prepare for surge production, simplify supply chains, and adapt to evolving threats. This prioritized framework recommends immediate action on facility conversion, labor training, and simplified technologies, followed by structural reforms and regulatory adjustments. Doctrinal shifts and extreme measures should be considered only in the event of a severe national emergency. By aligning industrial capacity with strategic needs, the United States can ensure readiness for future contingencies while preserving democratic principles and operational integrity.

Simple measures could mitigate current problems with surge capacity through bipartisan, easy-to-implement initiatives. First, prioritize investment in workforce training. Secondly, in the next budget, we will allocate funds and offer incentives to implement Warstopper expansion and facility conversion. Third, accelerate acquisition reform to support hybrid surge mechanisms and broaden competition. Most importantly, avoid politically and legally infeasible proposals that undermine democratic norms or statutory mandates. This framework should guide budget planning, industrial base assessments, and instructional deployment.

CONSEQUENCES OF IMPLEMENTING THE SELECTED SUGGESTIONS

The consequences of implementing the selected suggestions are arranged by the time frame in which they are likely to occur. The four time frames consist of the very short run, the short run, the long run, and the very long run. They are outlined one by one. It should be remembered that these consequences are expected to occur, although there are likely unintended or incidental consequences that may happen that are not described in this paper. As former Secretary of Defense Donald Rumsfeld stated in 2002, there are known knowns, known unknowns, and unknown unknowns.[635] Known knowns are things one knows one knows.[636] Known unknowns are things one knows one does not know.[637] Finally, unknown unknowns are things one does not know one does not know.[638] In volatile circumstances, the consequences one knows one knows can be planned for because one knows the known thing that is changing. Plans can be made for known unknown consequences because one knows of the existence of the unknown consequence. One can imagine what the unknown consequence looks like and how it will behave. Thus, it is only the unknown unknowns that one can neither imagine nor plan for.

`In general, the very short run, the short run, the long run, and the very long run do not have a specific time frame.[639] For this article, the very short run typically ranges from a single day to at most a month, while the short run is considered to run from at least a month to at most a year. In the very short run, little to nothing can be achieved. In the short run, primary missile manufacturers can increase output by using more labor or raw materials, but they do not have time to expand their manufacturing plants.[640] Third, the long run is deemed to be longer than a year but less than five years, although it could be longer depending on the circumstances.[641] [642] In the long run, fixed inputs vary, just like the variable inputs. However, it is possible, although not generally accepted, that some inputs may remain fixed in the long run due to their inherent nature. An example could be building a bridge over a significant river, where state and federal governments require numerous studies and permits to be obtained before production can begin. Although strictly speaking, from an economic perspective, this time period would be considered the short run. From a practical point of view, one could view the period as a considerable length of time. Finally, for this article, the very long run is defined as any period exceeding five to ten years. For example, if, from conception to production, it takes more than ten years to produce a next-generation jet airplane, this period could be considered the very long run. For example, in 2020, the United States Navy quietly began development of the next-generation carrier fighter, which was expected to be operational in the 2030s.[643] From the perspective of 2020, this time period could be construed as the very long run.

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[634] Seth G. Jones, *supra*, note 462.
[635] Daniel Sarewitz, Unknown Knowns, *Issues in Science and Technology* (Fall 2020), *available at* https://issues.org/known-unknowns-uncomfortable-knowledge-sarewitz/.
[636] *Id.*
[637] *Id.*
[638] *Id.*
[639] Will Kenton, Short Run: Definition in Economics, Examples, and How It Works, *Investopedia* (Jun. 30, 2025), *available at* https://www.investopedia.com/terms/s/shortrun.asp#:~:text=Adjust%20Labor%20Scheduling:%20Labor%20costs,broader%2C%20long-run%20strategy.
[640] *Id.*
[641] *See generally*, Mike Moffatt, The Short Run vs. the Long Run in Microeconomics, *ThoughtCo* (Sep. 20, 2018), *available at* https://www.thoughtco.com/the-short-run-vs-long-run-1146343#:~:text=Short%20Run%20vs.-,Long%20Run,that%20affect%20the%20production%20output.
[642] Paul Krugman, & Robin Wells, *supra*, note 387.
[643] Mallory Shelbourne, Navy Quietly Starts Development of Next-Generation Carrier Fighter; Plans Call for Manned, Long-Range Aircraft, *USNI News* (Aug. 19, 2020), *available at* https://news.usni.org/2020/08/18/navy-quietly-starts-development-of-

Consequences in the Very Short Run

In the very short run, very little can be achieved to solve the surge capacity problem. Primary missile manufacturers and their suppliers can make immediate adjustments, such as offering price discounts if applicable, changing component inventories, adjusting labor schedules, optimizing other variable inputs, and managing cash reserves.[644] Another thing that primary missile manufacturers may achieve in the very short term is to review the suggestions discussed above and determine if any of them can be implemented, even if only partially, in the very near future. On its face, this action may provide a missile manufacturer's reassurance that something is being achieved, if only superficially, to resolve the surge capacity problem.

Consequences in the Short Run

As stated previously, the short run is considered to last from more than a month to less than a year. During this period, the two highly likely suggestions, Suggestion #14 and Suggestion #20 in Table 21, could be implemented or at least initiated. With Suggestion #14, promoting labor force training that focuses on simple solutions to the surge capacity problem could be started in earnest. This would mark the beginning of a reevaluation process in which production activities are examined to identify ways to simplify missile production. If this suggestion is to be effective, a new approach to missile production should be adopted without unnecessarily disrupting current production methods. A task force could be established to investigate missile production techniques to identify opportunities for simplification. For example, if the input materials are physically located more than, say, six feet away from the assembly point of a missile, the component could be moved closer to the center of the production area. Another example would be scrutinizing a particular component, analyzing its construction to determine whether it could achieve the same functionality with fewer parts or simpler software. It is worth noting that robust software programs are preferred because they are significantly less likely to fail dramatically. Robust software programs are usually capable of gracefully handling error conditions without crashing.

Suggestion #20 in Table 21, adopting the United States' Warstopper Program and strategic elasticity, could enter its initial phases in the short run.[645] [646] The intent of the Defense Logistics Agency's Warstopper Program is to help the military access high-demand items in wartime, such as active missiles.[647] The program could be modified in the short term to ensure that active missiles are available when needed. The Warstopper Program is currently active; however, the GAO has determined that the program's goals are not outcome-oriented and lack quantifiable targets to assess performance.[648] Furthermore, the program's performance measures are not balanced across its goals and do not encompass all of its core activities.[649] In the short run, these limitations could be resolved using Eliyahu Goldratt's Theory of Constraints operations methodology.[650] The five steps in the Theory of Constraints include:

- ***Identify the Constraint:*** Find the part of the process that is causing the bottleneck.
- ***Exploit the Constraint:*** Get the most out of the constraint by ensuring it is always working on the most valuable tasks and is not idle.
- ***Subordinate Everything Else to the Constraint:*** Adjust all other parts of the system to support the constraint. They should not work faster than the constraint can handle.
- ***Elevate the Constraint:*** If the constraint is still limiting, find ways to improve its capacity.
- ***Go Back to Step One:*** Once a constraint is elevated, a new constraint will emerge. Repeat the process to achieve continuous improvement.

The GAO has identified the lack of quantifiable targets and the various performance measures as constraints.[651] The next three steps in Goldratt's theory are critical. The two constraints should be exploited, followed by ensuring that everything else in a Warstopper Program is subordinated to these constraints, and then elevating the constraints to discover ways to improve their capacity. The final step in the Theory of Constraints is to revisit the first step and identify any additional existing constraints. This can likely be achieved within a year or in the short term.

Although the moderately likely suggestions in Table 22 will probably achieve a modicum of success, it appears that Suggestion #12 is the only suggestion that could likely be successful. In other words, reevaluating just-in-time manufacturing procedures may help address the surge capacity problem in the short term. This suggestion would examine the active missile production process and determine whether, in the event of a surge, the primary missile could meet the surge output demands. If not,

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next-generation-carrier-fighter-plans-call-for-manned-long-range-aircraft#:~:text=This%20post%20has%20been%20updated,in%20the%20Indo-Pacific%20theater.

[644] Will Kenton, *supra*, note 639.

[645] Beth Reese, *supra*, note 585.

[646] GAO Staff, *supra*, note 586.

[647] *Id.*

[648] *Id.*

[649] *Id.*

[650] ELIYAHU GOLDRATT, THE GOAL: A PROCESS OF ONGOING IMPROVEMENT (North River Press, 40th Anniversary Edition, 2012).

[651] GAO Staff, *supra*, note 586.

then the primary manufacturer could find itself in a delicate position, having to explain to the military that its demands cannot be met. This outcome would be undesirable for military planners. The solution to the just-in-time manufacturing problem is to increase input inventory, which should be sufficient to meet the military's demands. An increase in inventory would entail additional costs for the primary missile manufacturer, but it would likely be worth it.

Consequences in the Long Run

For this article, the long run is defined as one to five years. When examining Suggestion #7, Suggestion #18, and Suggestion #3 in Table 22, it is apparent that these three suggestions could be achieved in one to five years. Suggestion #7 addresses converting existing manufacturing facilities to meet a surge in missile production. Suggestion #18 proposes replacing complex missiles with scalable designs. Finally, Suggestion #3 recommends that the market concentration ratio of 75.01 percent for Raytheon Corp. could be reduced if the three other companies in the active missile production market were given more contracts to produce active missiles.

One possibility, although unlikely, Raytheon Corp. could divest its missile production monopoly by selling or licensing its missile production technology to Lockheed Martin Corp., The Boeing Company, and Kongsberg Defence and Aerospace AS, thereby reducing the HHI for the primary active missile production market from 5,858.79 to a much lower figure. For example, if each of the four companies had a 25 percent market share, the HHI index would be 2,500.00. Although each company would still possess significant market power, no one company could be deemed a monopoly. If the United States awarded future primary missile production contracts to United States firms such as General Dynamics Corp., Hughes Corp, L3 Harris Technologies, Inc., and Northrup Grumman Corp., and all eight firms had market shares of 12.5 percent each, the HHI for the active primary manufacturing market would decrease to 1,250.00, a number much closer to a monopolistically competitive market than a highly concentrated oligopoly or even monopoly.[652]

Additionally, in the long run, primary missile manufacturers could make some inroads into the surge capacity problem by implementing the neutrally likely suggestions, specifically Suggestion #8, Suggestion #6, Suggestion #10, Suggestion #16, and Suggestion #13, as outlined in Table 23. These suggestions are feasible, provided that long lead times, scaling issues, and conceptual issues are taken into account. All the neutrally likely suggestions are legally permissible, but the industrial precedents are most mixed, except for Suggestion #6, where the industrial precedent is strong due to significant DOD investments. The problem with implementing the neutrally likely suggestions is that the strategic alignment for all five suggestions is mixed for various reasons, ranging from cultural resistance to bureaucratic inertia.

Thus, in the long run, or one to five years, implementing the neutrally likely suggestions will probably not result in a significant resolution of the surge capacity. Simply stated, there are too many factors that would inhibit the successful execution of the neutrally likely suggestions. The consequences would probably be marginal at best and ineffective or even detrimental at worst.

Consequences in the Very Long Run

In the very long run, or more than five years and less than ten years, Suggesting #9 in Table 24 seems doable because it takes a significant amount of time to reduce missile complexity. Systems have to be examined afresh, which is challenging to achieve when missile engineers are too focused on current technology. It is sometimes much easier to incrementally improve technology rather than examine technology from a new and disruptive perspective.[653] When disruptive technologies emerge in various markets, the issues with older technology become apparent.[654] Solutions that were previously overlooked now become evident.

As for Suggestion #4, reducing excessive city ordinances, as well as state laws and regulations, the likelihood of this occurring quickly is doubtful. Generally, legislative bodies require a significant amount of time to repeal ordinances, laws, and regulations. Studies are usually required when opposing parties are allowed to voice their opinions, either in favor of or against a piece of legislation. The study itself could take years to complete, and there is usually no guarantee that a study will be univocally in favor of repeal. Legislators will likely need to be educated by lobbyists on whether reducing legislative oversight is in the best interest of the community. In this era of increased regulatory scrutiny, the probability of reducing government supervision is slim to none.

Consequences for the Remaining Suggestions

The highly unlikely suggestions listed in Table 25 are what remain. These consist of seven suggestions that are infeasible, politically toxic, incompatible, misaligned, legally constrained, or even neglectful. Their legal viability is unclear, constitutionally limited, or illegal. There are no industrial precedents, and the strategic alignment is incompatible, not scalable, or politically destabilizing. This means that if any one of these suggestions were implemented, the effect would probably make the surge capacity problem worse

[652] Paul Krugman, & Robin Wells, *supra*, note 387.
[653] Clayton Christiansen, *supra*, note 553.
[654] *Id.*

rather than better. Thus, because of the negative consequences associated with the highly unlikely suggestions, it is reasonable to conclude that they should not be attempted or even planned.

Unintended Consequences

Although the unintended consequences are challenging to identify, one unintended consequence stands out from the rest. The existence of the surge capacity problem tends to limit the political and military ambitions of a nation's leadership. The reason is that there are not enough weapons available to conduct kinetic operations. On the other hand, if one or more of the suggestions discussed above were to be successful, it might enhance the military aspirations of some countries because the leadership would know that they could successfully fulfill their military objectives and goals. In a world that desires peace, addressing the surge capacity problem could lead to increased military expenditures and conflicts. From a peaceful perspective, solving the surge capacity problem would be counterproductive. If the suggestions were to unscramble the surge capacity problem, then such a result would have to be tempered with the wisdom not to exploit the solution.

CONCLUSIONS

This concluding section is divided into nine subsections. The first subsection addresses the rebuilding of missile surge capacity. The second subsection talks about surge capacity as a strategic need. In the third subsection, systematic constraints are described across various missile classes. In the fourth subsection, the structural root causes of surge failure and their strategic implications are listed. Fifth, strategic misalignment and organizational fragility are outlined. Sixth, specific recommendations for structural reform are highlighted. The seventh subsection examines global lessons and allied integration. The eighth subsection reviews scalability. The final subsection expresses the closing thoughts of the authors. Surge capacity is not a wartime activity. The goal is not about building more missiles, but creating a manufacturing environment that can adapt, scale, and endure. Surge capacity is a systematic vulnerability rooted in industrial structure, regulatory complexity, technological ambition, and workforce fragility. There is no royal road to solving the surge capacity problem. It takes work, hard work.

Rebuilding Missile Surge Capacity

The United States faces a surge capacity crisis in its missile production enterprise, which is not a transient manufacturing bottleneck, nor a problem that can be solved through incremental adjustments. It is structural in nature and institutionally rooted in years of industrial consolidation, regulatory inertia, strategic doctrine misalignment, and managerial fragmentation, now posing a threat to the United States's deterrence and the resilience of allied defense postures.

Surge Capacity as a Strategic Need

Surge capacity is not a wartime contingency, but a peacetime obligation. The ability to replenish missile inventories at scale and speed is foundational to modern deterrence, especially in an era of high-tempo, multi-domain conflict. Recent wars in Ukraine and the Middle East have demonstrated that adversaries like Russia and Iran possess greater surge elasticity, enabling them to sustain operations and saturate defenses. In contrast, the United States and its allies have struggled to match battlefield attrition with industrial replenishment, revealing a dangerous lag between consumption and production.

Systemic Constraints Across Missile Classes

Across all missile categories, air-to-air, air-to-surface, surface-to-air, and surface-to-surface. the surge vulnerability is pervasive. Tactical systems like the Stinger and RAM exhibit resilience due to modularity and scalable production. However, strategic platforms such as the AIM-120 AMRAAM, RIM-161 SM-3, and MIM-104 Patriot are structurally surge-inert, constrained by high costs, export licensing friction, specialized components, and limited production throughput. Legacy systems like the AIM-7 Sparrow and AGM-65 Maverick are technically obsolete yet remain in allied inventories, further complicating integration and sustainment.

Structural Root Causes of Surge Failure and Their Strategic Implications

The inability to scale missile production stems from 12 interlocking constraints. The surge capacity problem is not merely a matter of production speed. It is a complex interplay of industrial concentration, regulatory friction, facility limitations, design complexity, and labor dynamics. These twelve causes collectively explain why the United States missile manufacturing sector cannot rapidly respond to sudden spikes in demand. These are not isolated issues, but they are systemic and mutually reinforcing.

- ***Market Concentration**:* The industry is dominated by a few firms, Raytheon alone controls over 75% of active missile production. The Herfindahl-Hirschman Index (HHI) exceeds 5,800, indicating monopoly-level concentration. This reduces competitive pressure to expand capacity and creates bottlenecks when demand surges.
- ***Local and State Regulatory Barriers**:* Zoning laws, environmental ordinances, and permit requirements at the city and state levels can delay or prevent facility expansion. Even unused or underutilized plants require approvals that may not align with urgent defense needs.

Surge Capacity Issues for Selected United States Active Missiles

- ***Federal Laws and International Treaties**:* Export controls (e.g., AECA, MTCR), arms reduction treaties (e.g., START, SALT), and international non-proliferation agreements constrain missile production and distribution. These legal frameworks limit flexibility and complicate multinational manufacturing partnerships.
- ***Physical Facility Limitations**:* Existing plants may lack the square footage or infrastructure to scale production. Reactivating dormant facilities requires time, permits, and retrofitting, none of which are surge-responsive without federal intervention.
- ***Innovation Bottlenecks**:* Advanced propulsion, guidance, and warhead technologies drive up cost and complexity. While AI and precision targeting enhance capability, they also slow production and increase dependency on niche components.
- ***Missile Complexity**:* Multi-mode guidance systems, hyperspectral sensors, and integrated radar-IR architectures make modern missiles harder to build quickly. Complexity increases cost, reduces modularity, and limits scalability.
- ***Engineering Design Culture**:* Engineers often prioritize innovation over manufacturability. Without rigorous risk assessment and cross-disciplinary oversight, new designs may be elegant but surge-inert. Ethical and operational foresight is usually lacking.
- ***Department of Defense Acquisition Constraints**:* The DOD's acquisition system is slow, bureaucratic, and cautious. Joint Capabilities Integration and Development System (JCIDS) modernization and contracting reforms are underway, but surge responsiveness remains limited by procedural inertia and fragmented oversight.
- ***Just-in-Time Manufacturing**:* JIT systems minimize inventory and rely on precise forecasting. They are efficient in peacetime but brittle under wartime surge conditions. A sudden demand for thousands of missiles cannot be met by a supply chain designed for lean throughput.
- ***Lean Manufacturing Limitations**:* Lean practices discourage idle capacity and buffer stock, both of which are essential for surge responsiveness. The emphasis on waste reduction and continuous flow undermines the ability to absorb demand shocks.
- ***Labor Force Challenges**:* The defense sector faces an aging workforce, skills mismatch, outdated training pipelines, and long security clearance delays. Without rapid onboarding and cross-training, labor shortages become production chokepoints.
- ***Union Relations and Activism**:* Rigid work rules and union political activism can hinder flexibility. While collective bargaining protects workers, it may also limit the rapid reassignment of roles or the redesign of facilities for repurposing during surge scenarios.

Strategic Misalignment and Organizational Fragility

The current defense industrial base is misaligned with the strategic demands of modern warfare. Deterrence doctrine emphasizes rapid response and sustained conflict, yet production architecture remains optimized for peacetime efficiency rather than wartime elasticity. The absence of anticipatory surge planning, modular design, and integrated allied procurement pipelines has created a brittle ecosystem. The Surge Readiness Index (SRI) reveals that surge failure is not anomalous, but is predictable, quantifiable, and remediable.

Recommendations for Structural Reform

To restore surge credibility and strategic depth, the following reforms are essential:

- ***Institutionalize anticipatory contracting*** through multi-year procurement and embedded surge clauses.
- ***Modernize legacy systems*** with modular propulsion and electronics to restore viability.
- ***Diversify supplier networks*** to mitigate single-source dependencies and regional chokepoints.
- **Deploy flexible manufacturing systems (FMS)** using CNC tools, robotic automation, and reconfigurable infrastructure.
- ***Reform DOD acquisition*** to prioritize surge responsiveness, not just cost efficiency.
- ***Invest in workforce development*** with training focused on simplicity, cross-functionality, and rapid onboarding.
- ***Reevaluate lean and JIT practices*** to allow for strategic inventory buffers and production slack.
- ***Expand Warstopper-like programs*** to preserve idle lines and preposition tooling for rapid activation.
- ***Simplify missile designs*** to reduce costs, increase manufacturability, and enable mass production.
- ***Aligning strategic goals with industrial capacity***, thereby ensuring that credible replenishment timelines support deterrence.

Global Lessons and Allied Integration

Adversaries like China have adopted vertically integrated, state-controlled defense production models that prioritize surge readiness. While the United States should not emulate authoritarian centralization, it should learn from these models by embedding modularity, dual-use infrastructure, and strategic stockpiling into its industrial base. Allies such as Israel, Ukraine, Japan, and Australia are already pivoting toward indigenous production and co-development to hedge against the United States' surge limitations. NATO's Defense Production Action Plan and DIANA initiative are promising but require deeper integration, shared procurement frameworks, and unified surge hierarchies.

Scalability
The future of missile warfare favors scalable, cost-effective munitions over highly complex boutique and high-cost platforms. The United States may need to shift from exquisite systems to attrition-ready arsenals that are modular, interoperable, and rapidly replenishable. This requires not only technical redesign but a cultural shift in how the defense community defines value, risk, and readiness.

Closing Thoughts
Surge capacity is not a wartime luxury: it is a peacetime obligation. The goal is not about building more missiles, but creating a manufacturing environment that can adapt, scale, and endure, which will be the actual test of deterrence in the 21st century. The United States should now meet that challenge by adopting modular manufacturing, anticipatory contracting, and strategic alignment. If the United States fails in this endeavor, it risks entering future conflicts that lack depth and reliable supply chains, ultimately eroding our allies' confidence. Reengineering missile production for elasticity, resilience, and interoperability is essential to preserving operational credibility and strategic deterrence in today's multi-domain escalation environment.

Surge capacity is a systemic vulnerability rooted in industrial structure, regulatory complexity, technological ambition, and workforce fragility. The next war will likely not respect procurement cycles. Instead, it will probably demand readiness, resilience, and reform. Without immediate and sustained investment in surge capacity, the United States risks strategic obsolescence, not because it lacks innovation, but because it cannot scale. The United States cannot follow an incrementalist paradigm, as current conditions show it is inappropriate. The United States' strategic doctrine needs to change by reimagining missile production as a strategic function rather than a logistical afterthought. Without deliberate reforms across these twelve domains listed above, the United States risks entering future conflicts with insufficient missile inventories and an industrial base incapable of rapid replenishment. Strategic readiness demands not just innovation, but scalability, modularity, and resilience.

APPENDIX A: UNITED STATES MISSILE NAMING CONVENTION
The naming of United States missiles involves a formal Tri-Service designation system that uses letters to denote status, launch environment, mobile type, vehicle type, design number, series, and configuration number. Common names, such as Tomahawk or Harpoon, succeed these naming conventions. Modern missiles often employ acronyms such as TOW or JASSM. In other words, the system combines formal codes with popular names, balancing official standardization with marketing and ease of use. Here is the naming system.[655]

- **Status Prefix, Blank If in Production:**
    - **C:** Captive
    - **D:** Dummy
    - **J:** Special Test, Temporary
    - **N:** Special Test, Permanent
    - **X:** Experimental
    - **Y:** Prototype
    - **Z:** Planning
- **First Letter (Launch Environment):**
    - **A:** Air (Air-launched)
    - **B:** Multiple
    - **C:** Coffin
    - **F:** Individual
    - **G:** Surface
    - **H:** Silo Stored
    - **L:** Silo Launched
    - **M:** Mobile
    - **P:** Soft Pad
    - **R:** Ship
    - **S:** Space
    - **U:** Underwater

[655] Aero Space Web Staff, US Rocket & Missile Designation System, *AerospaceWeb.org* (n.d.), *available at* https://aerospaceweb.org/question/weapons/q0075.shtml#:~:text=Design%20Number,Jeff%20Scott%2C%2028%20April%202002.

- **Second Letter (Mission/Type):**
    - **C:** Transport
    - **D:** Decoy
    - **E:** Electronic Warfare or Special Electronic Equipment
    - **G:** Surface Attack
    - **I:** Aerial or Space Intercept
    - **L:** Launch Detection or Surveillance
    - **M:** Scientific or Calibration
    - **N:** Navigation
    - **Q:** Drone or Target
    - **S:** Space Support
    - **T:** Training
    - **U:** Underwater Attack
    - **W:** Weather
- **Third Letter (Vehicle/Platform):**
    - **B:** Booster
    - **M:** Guided Missile or Drone
    - **N:** Probe
    - **R:** Rocket
    - **S:** Satellite
- **Design Number:** This number indicates the sequential order of the weapon within that vehicle type.
- **Series:** This letter specifies a significant variant of the weapon, "A" being the initial production model, with new models being indicated by subsequent letters. The letters "I" and "O" are usually skipped to avoid confusion with the numbers "1" and "0", respectively.
- **Configuration Number:** This number specifies a minor subvariant of the weapon.

For example, consider the AIM-7P Sparrow. There are three letters in the missile's name, signifying that the status prefix is blank, and the missile is in production. The letter "A" indicates that the missile is launched from the air. The letter "I" shows that the missile is intended to intercept another aircraft that is in the air. The third letter "M" signifies that the weapon is a missile. The letter "P" designates the major variant. There is no minor subvariant configuration number. The common name for the missile is "Sparrow."

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