WHITE PAPER

Digital Maritime Sustainment Ecosystem

Enabling Fleet Readiness Through AI-Enabled Engineering and Distributed Advanced Manufacturing

SNOWBIRD ADDITIVE MOBILE MANUFACTURING TECHNOLOGY X MELTIO ENGINE BLUE

SAMM Tech White Paper - Version 1 June, 2026

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EXECUTIVE SUMMARY

Modern maritime operations depend upon the availability and readiness of complex platforms operating across geographically dispersed environments. Sustainment organizations increasingly face challenges associated with aging fleets, supply chain disruptions, diminishing manufacturing sources, long procurement lead times, and contested logistics environments. Traditional sustainment models rely heavily on centralized production and warehousing, often resulting in extended downtime when critical components become unavailable.

Advances in artificial intelligence, digital engineering, and additive manufacturing present an opportunity to fundamentally transform maritime sustainment. By integrating AI-enabled part identification, digital twins, automated engineering workflows, and deployable advanced manufacturing systems, maintenance organizations can transition from reactive supply-chain-driven support to proactive, digitally enabled sustainment.

ADVANCES IN ARTIFICIAL INTELLIGENCE, DIGITAL ENGINEERING, AND ADDITIVE MANUFACTURING PRESENT AN OPPORTUNITY TO FUNDAMENTALLY TRANSFORM MARITIME SUSTAINMENT

This paper outlines a **Digital Maritime Sustainment Ecosystem** capable of identifying, reproducing, repairing, and manufacturing mission-critical components at the point of need. Through the integration of digital engineering tools and expeditionary manufacturing technologies, maritime operators can reduce vessel downtime, mitigate obsolescence risks, and improve fleet readiness while decreasing dependence on traditional supply chains.

THE MARITIME SUSTAINMENT CHALLENGE

Maritime platforms are expected to remain operational for decades while supporting increasingly demanding mission requirements. Throughout their service life, sustainment organizations encounter persistent challenges:

- Long lead times for replacement parts
- Supplier attrition and component obsolescence
- Increasing inventory management costs
- Aging technical data packages
- Limited manufacturing capacity for low-volume components
- Operational impacts from contested logistics environments

Many replacement parts are no longer produced by original suppliers or require specialized manufacturing processes that are difficult to source. Even when parts remain available, procurement cycles may extend for months due to contracting, manufacturing, and transportation delays.

As a result, maintenance personnel are often forced to wait for replacement components while operational assets remain unavailable. This challenge becomes increasingly significant during deployed operations where access to traditional supply chains may be constrained or disrupted.

To address these challenges, sustainment organizations require a more agile and resilient approach to component replacement and repair.

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DIGITAL MARITIME SUSTAINMENT ECOSYSTEM

The proposed **Digital Maritime Sustainment Ecosystem** combines advanced digital engineering technologies with distributed manufacturing capabilities to create an end-to-end sustainment workflow.

The ecosystem consists of four primary elements:

- AI-Assisted Part Identification - Maintenance personnel use handheld imaging devices to capture photographs of damaged or obsolete components. Artificial intelligence algorithms analyze component geometry and compare it against digital models and historical maintenance records to determine:
  - Part identification
  - Failure characteristics
  - Repair feasibility
  - Manufacturing requirements

  This capability reduces reliance on manual engineering assessments while accelerating the decision-making process.

- Digital Twin Integration - A digital representation of the platform provides contextual awareness for sustainment operations. Digital twin technology enables maintainers to:
  - Verify component geometry
  - Analyze wear patterns
  - Evaluate installation constraints
  - Track maintenance history
  - Support predictive maintenance initiatives

  The digital twin serves as the authoritative source of technical information throughout the sustainment lifecycle.

- Automated Engineering and Manufacturing Planning - Following identification, the system automatically generates a manufacturable digital model and develops an optimized production strategy. AI-enabled workflows evaluate:
  - Material selection
  - Manufacturing process suitability
  - Build orientation
  - Toolpath generation
  - Inspection requirements

  This automation dramatically reduces engineering effort while improving manufacturing consistency and repeatability.

- Distributed Manufacturing - Manufacturing packages are transmitted directly to advanced manufacturing systems located at shipyards, maintenance depots, naval installations, or expeditionary operating locations.

  This distributed approach eliminates many of the delays associated with traditional procurement and transportation processes.

HYPOTHETICAL USE CASE

Consider a maritime platform undergoing routine maintenance at a regional support facility.

During inspection, technicians discover a cracked aluminum mounting bracket supporting a critical hydraulic subsystem. Further evaluation determines that the component must be replaced before the platform can return to operational service.

Under a traditional sustainment model, replacement would require:

- Component identification
- Supply chain sourcing
- Procurement approval
- Manufacturing by a third-party supplier
- Transportation and delivery

The entire process could require several months.

Using the **Digital Maritime Sustainment Ecosystem**, the workflow proceeds differently. Technicians capture images of the damaged component using a handheld device. AI-enabled sotware identifies the part and compares it against digital twin data to verify geometry and installation requirements.

The system automatically generates a digital model and determines that additive manufacturing is the optimal production method. Engineering algorithms select an appropriate aluminum alloy and generate manufacturing instructions based on structural and operational requirements.

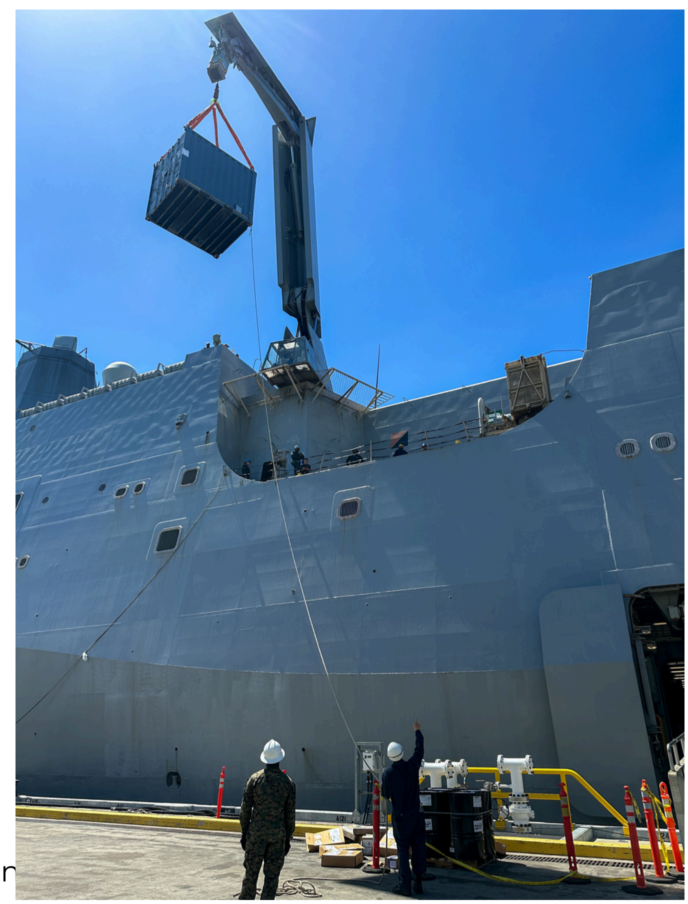
The manufacturing package is transmitted directly to a deployable advanced manufacturing system located at the maintenance facility. The replacement component is produced, inspected, and installed within days rather than months. The platform returns to operational status with minimal disruption to mission schedules.

ADVANCED MANUFACTURING AT THE POINT OF NEED

A key enabler of this ecosystem is deployable advanced manufacturing technology capable of producing both metal and polymer components in operational environments. Modern directed energy deposition systems provide several capabilities particularly relevant to maritime sustainment:

- Expanded Material Compatibility - Recent advancements have improved processing of traditionally difficult materials, including:
  - Aluminum alloys
  - Copper alloys
  - Stainless steels
  - Corrosion-resistant materials

  These materials are widely used throughout maritime platforms due to their structural performance, thermal properties, and corrosion resistance.



- Improved Process Reliability - Advanced deposition systems incorporate:
  - Enhanced wire feeding systems
  - Improved thermal management
  - Greater process stability
  - Increased operational uptime

  These improvements are critical for field-deployable manufacturing systems operating in demanding environments.

- Real-Time Process Monitoring - Integrated monitorin
  - Melt pool observation
  - Process diagnostics
  - Quality assurance data
  - Manufacturing traceability

  The resulting digital records support qualification efforts and establish confidence in manufactured components.

- Hybrid Material Production - In addition to metal manufacturing, integrated polymer and composite capabilities enable production of:
  - Covers and enclosures
  - Fixtures and tooling
  - Ducting components
  - Non-structural replacement parts

  This flexibility broadens the range of sustainment applications supported by a single manufacturing platform.

OPERATIONAL BENEFITS

The **Digital Maritime Sustainment Ecosystem** delivers benefits across multiple dimensions.

- Increased Fleet Readiness - Reducing replacement part lead times from months to days directly improves platform availability and mission readiness.
- Supply Chain Resilience - Distributed manufacturing decreases reliance on centralized suppliers and mitigates the impact of supply chain disruptions.
- Obsolescence Mitigation - Digital inventories and reverse engineering capabilities provide a pathway for sustaining legacy systems long after traditional suppliers have exited the market.
- Reduced Logistics Burden - Producing components closer to the point of need reduces transportation requirements and inventory storage costs.
- Enhanced Engineering Efficiency - Automated workflows allow engineering personnel to focus on complex sustainment challenges rather than routine component recreation.
- Support for Distributed Maritime Operations - The ability to manufacture parts at forward operating locations aligns with emerging concepts focused on agility, survivability, and decentralized logistics.

FUTURE VISION

The convergence of artificial intelligence, digital engineering, and advanced manufacturing is creating new opportunities for maritime sustainment.

Future developments may include:

- Automated damage assessment
- Predictive maintenance recommendations
- Closed-loop manufacturing control
- Autonomous quality assurance
- Fleet-wide digital inventories
- Networked manufacturing across multiple operating locations

Together, these capabilities will enable sustainment organizations to transition from reactive maintenance models to proactive readiness ecosystems.

CONCLUSION

Maritime sustainment is entering a period of significant transformation. Traditional supply-chain-dependent approaches are increasingly challenged by aging fleets, component obsolescence, and operational demands that require greater agility and resilience.

A **Digital Maritime Sustainment Ecosystem** integrates AI-enabled engineering, digital twins, automated manufacturing workflows, and distributed advanced manufacturing to address these challenges directly. By enabling rapid identification, reproduction, repair, and production of mission-critical components at the point of need, the ecosystem reduces downtime, enhances fleet readiness, and strengthens supply chain resilience.

As maritime operators seek innovative solutions to improve operational availability and support distributed operations, digitally integrated advanced manufacturing offers a practical and scalable path toward the future of sustainment.

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