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SAHA AKADEMİ MBA YÖNETİCİ GELİŞTİRME PROGRAMI

Advanced Manufacturing of Composite Aerospace Structures via Automated Fiber Placement

MBA Project Proposal
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ARAŞTIRMA PROJESİ UYGUNLUK FORMU

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ADVANCED MANUFACTURING OF COMPOSITE AEROSPACE STRUCTURES VIA AUTOMATED FIBER PLACEMENT

(PROJECT PROPOSAL FORM)

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Abstract

This proposal outlines a project aimed at demonstrating the feasibility and benefits of utilizing Automated Fiber Placement (AFP) as a manufacturing method for advanced composite aerospace structures. The project will focus on increasing the efficiency and quality of manufacturing complex-shaped, monolithic composite aerospace structures. Additionally, it will emphasize optimized material utilization and enhanced structural performance. By utilizing a robotic AFP system with advanced control and automation capabilities, integrating advanced simulation and design tools, and exploring a broad range of composite materials, this project aims to address the limitations of traditional composite manufacturing methods, leading to reduced production time, cost, and material waste with improved build quality.

Key Words: Automated Fiber Placement, Advanced Composite Manufacturing, Robotic Systems, Manufacturing Efficiency and Cost Reduction, Material Utilization Optimization

1. Introduction

The aerospace industry consistently demands high-performance, lightweight structures with increasingly complex geometries. Traditional composite manufacturing methods often present limitations in terms of manufacturing and structural efficiency, cost-effectiveness, build quality and material waste. Automated Fiber Placement (AFP) technology offers a promising solution by enabling the precise and automated fabrication of complex composite components [1-4]. This project aims to demonstrate the capabilities of AFP for manufacturing aerospace structures, specifically focusing on monolithic construction and optimized material utilization. The project will use a robotic AFP system with advanced control and automation capabilities, integrating advanced simulation and design tools to optimize fiber placement and structural integrity (Figure 1-3).

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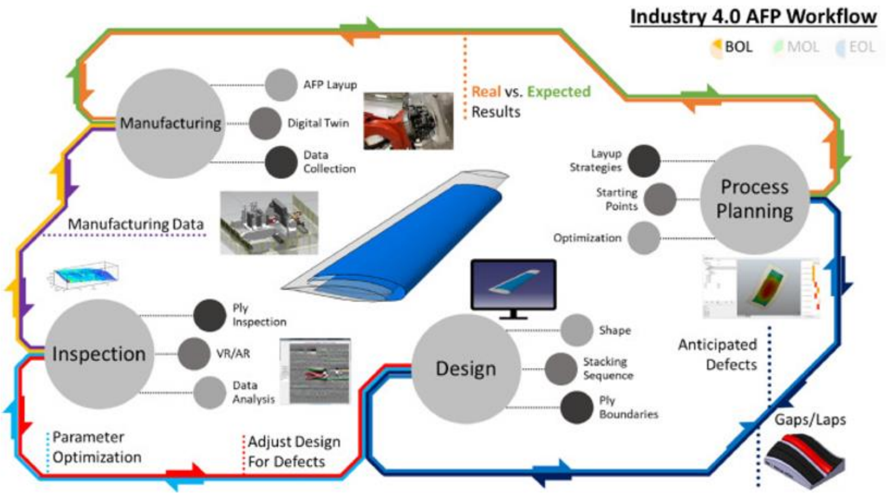

Figure 1. Graphical representation of closed-loop AFP workflow [4]

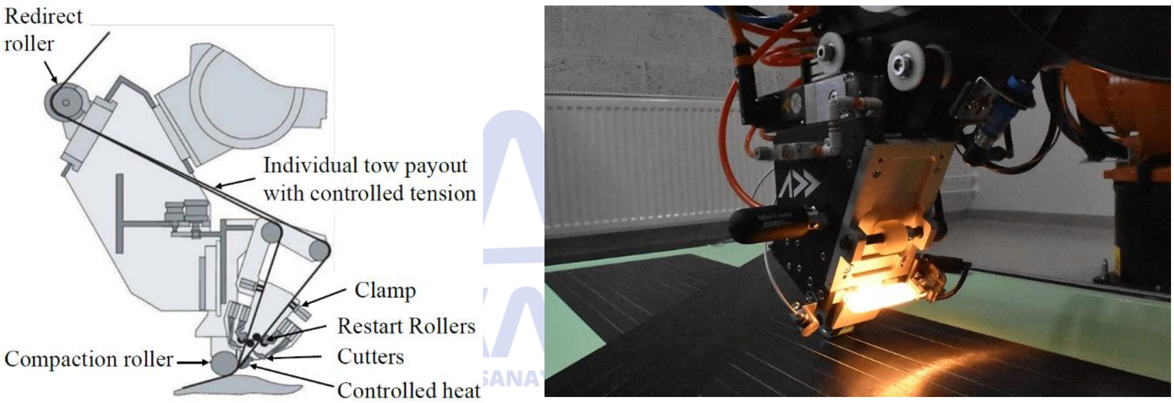

Figure 2. Schematic of a typical AFP machine head [5]

Figure 3. Automated Fiber Placement application [6]

2. Project Aim

The primary aims of this project are:

- To demonstrate the feasibility and benefits of utilizing Automated Fiber Placement (AFP) manufacturing method for aerospace structures,
- To increase the efficiency and quality of manufacturing complex-shaped, monolithic composite aerospace structures,
- To focus on optimized material utilization and enhanced structural performance,
- To address the limitations of traditional composite manufacturing methods by reducing production time, cost, and material waste.

3. Project Scope

The scope of this project includes:

- Focus on the utilization of a robotic AFP system with advanced control and automation capabilities,
- Integration of advanced simulation and design tools for optimizing fiber placement and structural integrity,
- Demonstration of the system's ability to produce complex, monolithic aerospace structure,

- Exploration of a broad range of composite materials, including thermosets, thermoplastics, and dry fabrics, leveraging the inherent material flexibility of AFP systems.

4. Target Audience

The target audience for this project includes:

- Aerospace industry composite structure designers and manufacturers,
- Research institutions and universities focused on advanced composite applications,
- NATO and defense stakeholders, particularly those engaged with NATO STO (Science & Technology Organization),
- Other industries seeking advanced automation solutions for composite fabrication.

5. Project Methodology and Work Plan

The project will employ the following methodology and work plan:

- Research and development of advanced robotic AFP techniques.
- Design and Simulation:
    - Selection of complex aerospace structural designs.
    - Detailed CAD modeling and finite element analysis (FEA).
    - Development of optimized fiber placement patterns using specialized software.
- Material Characterization:
    - Selection of appropriate composite materials (e.g., carbon fiber, resin systems).
    - Material testing to determine mechanical properties and process parameters.
- AFP Manufacturing:
    - Generation of AFP toolpaths based on design and material data.
    - Manufacturing of demonstrator components using the existing AFP system.
    - Real-time process monitoring and quality control.
- Testing and Evaluation:
    - Non-destructive testing (NDT) to ensure component integrity.
    - Mechanical testing (e.g., tensile, compression, flexural, buckling) to validate structural performance.

- Project phases and timeline:
    - Phase 1: Design and Optimization for Manufacturing strategies (Months 1-4)
    - Phase 2: AFP Toolpath Development and Simulation (Months 5-8)
    - Phase 3: Component Manufacturing and Quality Control (Months 9-12)
    - Phase 4: Testing (Months 13-16)

6. Technical Background and Key Innovations

This project is based on recent advancements in AFP hardware and software technologies that enable highly controlled placement of composite tows over complex geometries. The technical aspects listed below will be crucial to the planned study:

- AFP System Specifications:
    - Multi-axis robotic AFP system with compaction rollers and independent tape cutting mechanisms.
    - Tow width variability (e.g., 1/8" to 1/2") enabling localized steering and coverage optimization.
    - Closed-loop feedback control integrating fiber placement sensors and laser inspection systems for real-time defect monitoring.
    - Heated compaction rollers for in-situ consolidation of thermoset and thermoplastic prepregs.
- Fiber Steering and Tow Path Optimization:
    - Implementation of curvilinear fiber paths to align reinforcement along principal stress directions, enhancing stiffness-to-weight ratio.
    - Use of automated tow-drop strategies to mitigate overlaps and gaps, leveraging continuous curvature and blended layer transitions.
    - Application of minimum-radius-of-curvature constraints and buckling avoidance criteria to enable defect-free deposition on tight radii and double-curved surfaces.
- Digital Twin and Simulation Integration:
    - Development of a digital twin framework coupling finite element structural simulations with AFP process simulations.

    - Incorporation of ply-level deformation modeling to predict wrinkles and bridging defects during lay-up.
    - Process-aware path planning using multi-physics simulations (thermal, mechanical) to guide toolpath generation and ensure consolidation quality.
- Materials and Processing Parameters:
    - Processing of carbon/epoxy thermoset prepregs and carbon/PEEK thermoplastics.
    - Investigation of in-situ consolidation temperature, optimal pressure ranges, and lay-up speed impacts on interlaminar bonding.
    - Characterization of degree of cure, void content, and fiber volume fraction using thermal analysis (DSC, TGA) and microscopy techniques.
- Advanced Inspection and Quality Assurance:
    - Use of automated optical scanning and ultrasonic phased array systems to identify manufacturing defects such as fiber misalignment, incomplete consolidation, delamination or porosity.
    - Real-time control using machine learning-based defect detection algorithms trained on AFP process sensor data.
- Benchmarking Against Traditional Methods:
    - Quantitative comparison against hand lay-up and tape lay-up techniques in terms of deposition rates (kg/hr or m^2/hr), material utilization efficiency, dimensional tolerances (e.g., ±0.5 mm over 2 m span), surface quality (Ra roughness in µm), production cycle time reduction.

7. Expected Outcomes

The expected outcomes of this project include:

- A fully functional robotic AFP system for monolithic aircraft structure manufacturing.
- Optimized fiber placement strategies for improved structural performance
- Demonstrated reduction in manufacturing time, weight, and cost compared to traditional methods.
- Improved structural integrity and performance of aerospace components.

8. Project Budget

We're aiming to manufacture major structural components (fuselage sections, wings, tail sections) of an Anka-sized UAV. We assume access to an existing industrial-grade AFP machine. Carbon fiber and high-performance resin systems will be used. We assume an existing facility is used. The estimated budget is $1,215,000, which is broken as follows:

Personnel (Months 1-16):

- Project Coordinator (1): $120,000
- Composite Engineer (1): $90,000
- Robotics/Automation Engineer (1): $90,000
- Technician (1): $80,000
- Total Personnel: $380,000

Materials:

- Carbon Prepreg Tows: $200,000
- Consumables (release agents, etc.): $20,000
- Total Materials: $220,000

Software:

- CAD/CAM Software Licenses: $15,000
- FEA Software Licenses: $30,000
- AFP Programming Software: $30,000
- Total Software: $75,000

Testing and Analysis:

- NDT (ultrasonic, etc.): $100,000
- Mechanical Testing (tensile, compression, etc.): $100,000
- Buckling test: $50,000
- Total Testing: $250,000

Other Expenses:

- AFP Machine Maintenance/Operation: $80,000
- Prototype Tooling: $80,000
- Travel (conferences, etc.): $30,000
- Contingency (~10%): $100,000
- Total Other Expenses: $290,000

Total Project Budget:

- $380,000 (Personnel) + $220,000 (Materials) + $75,000 (Software) + $250,000 (Testing) + $290,000 (Other) = **$1,215,000**

9. Risks and Mitigation

The project acknowledges the following risks and proposes the corresponding mitigation strategies:

Risk: Achieving precise fiber placement on complex 3D geometries.

- **Mitigation:** Implement advanced path planning algorithms, utilize high-resolution simulation tools, conduct extensive offline programming and simulation, and implement real-time process monitoring and control systems.

Risk: Material defects (gaps, overlaps, fiber wrinkling) during AFP manufacturing.

- **Mitigation:** Conduct thorough material characterization, optimize process parameters (temperature, pressure, speed), implement real-time process monitoring with in-situ quality control, and perform rigorous NDT.

Risk: Insufficient personnel resources or expertise.

- **Mitigation:** Provide necessary training and consider collaborating with external experts if needed.

Risk: Mechanical testing failures due to improper test setup or equipment malfunction.

- **Mitigation:** Develop detailed test procedures, ensure test equipment is calibrated, and conduct preliminary test runs.

10. Project Duration

The total project duration is given as follows:

- Start Date: January 1, 2025
- End Date: April 30, 2026
- Total Duration: 16 Months

11. Resources

Financial resources can be obtained from TUBITAK, SSB and though financial incentives and support provided by main integrators within the defense ecosystem. The project will utilize the following resources:

Existing AFP Machine and Infrastructure:

- Access to an industrial-grade robotic Automated Fiber Placement (AFP) system with multi-axis capabilities.
- Dedicated manufacturing space with environmental control for composite fabrication.

Software and Computational Resources:

- Advanced CAD/CAM software for composite design and toolpath generation (e.g., Siemens NX, CATIA Composites).
- Finite Element Analysis (FEA) software for structural analysis and simulation (e.g., ANSYS, ABAQUS).
- AFP programming and simulation software (e.g., VERICUT Composites, FiberSIM).

Materials and Testing Equipment:

- Supply of carbon fiber prepreg tows, resin systems, and dry fabrics.
- Material characterization equipment (e.g., tensile and compression testing machine, DSC).
- Non-destructive testing (NDT) equipment (e.g., ultrasonic testing, infrared thermography testing).
- Mechanical testing equipment (e.g., tensile, compression, flexural, buckling test rigs).

Personnel:

- Experienced composite engineers with expertise in AFP technology and material characterization.
- Robotics and automation engineers with knowledge of robotic programming and control systems.
- Skilled technicians with experience in composite manufacturing and testing.

Technical Documentation and Standards:

- Access to relevant aerospace industry standards and specifications (e.g., ASTM, ISO).

12. Evaluation Criteria

The project's success will be evaluated based on the following criteria:

Manufacturing Efficiency and Quality:

- Dimensional accuracy and surface quality of manufactured components.
- Consistency and repeatability of the AFP process.
- Reduction in manufacturing time compared to traditional methods.

- Minimization of material waste during manufacturing.

Structural Performance:

- Achievement of desired mechanical properties (tensile strength, compression strength, flexural strength, etc.).
- Validation of structural integrity through NDT and mechanical testing.
- Successful completion of buckling tests.
- Correlation between FEA predictions and experimental results.
- Weight reduction of the manufactured parts when compared to traditional manufacturing methods.

Material Utilization:

- Optimization of fiber placement patterns for maximum structural efficiency.
- Demonstrated ability to process a variety of material types using the AFP system.

Process Optimization and Automation:

- Effectiveness of developed AFP toolpaths and process parameters.
- Functionality and reliability of the robotic AFP system.
- Efficiency of the design-to-manufacturing workflow.
- Accuracy of real-time process monitoring and control.

Project Management:

- Adherence to the project timeline and budget.
- Effectiveness of risk management and mitigation strategies.

Technology Transfer and Knowledge Dissemination:

- Publication of research findings in technical reports and journals.
- Presentation of project results at conferences and industry events.

13. Conclusion

This project demonstrates the significant potential of Automated Fiber Placement (AFP) as a transformative manufacturing technology for advanced composite aerospace structures. By leveraging robotic automation, integrated simulation tools, and precise material placement, AFP enables the efficient production of complex, monolithic components with superior structural integrity. The approach not only reduces production time, material waste, and overall cost but also ensures high repeatability and build quality. These findings highlight AFP as a key enabler for the next generation of high-performance, cost-effective aerospace manufacturing solutions.

14. Future Work and Recommendations and Strategic implications for the Turkish Defense Industry

Building on the promising results of this project, future work should focus on the full-scale implementation of AFP in real-world aerospace manufacturing environments. This includes testing under operational load conditions, integration with digital twin technologies, and expanding the material database for AFP compatibility. Further development of user-friendly design and simulation tools will support wider industry adoption. It is also recommended to explore hybrid manufacturing approaches combining AFP with other automated methods to address highly intricate geometries and multifunctional material requirements.

For the Turkish defense industry, AFP presents a strategic opportunity to localize the production of lightweight, high-performance components for UAVs, missile systems, and advanced aircraft. Its integration can reduce foreign dependency, enhance supply chain resilience, and accelerate defense innovation. Close collaboration between leading firms (e.g., TUSAŞ, ROKETSAN, BAYKAR), research centers, and universities will be key to tailoring AFP solutions to national defense needs.

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