Design Document

Based on the team's first biweekly report covering March 24 - April 6, 2025 for the Smart Maintenance Platform for Aero Engine Industrial Equipment project, the following sections of the Design Document can be developed:

1. Document Information

1.1 Document Control Information

- **Document Title:** Smart Maintenance Platform for Aero Engine Industrial Equipment - Design Document
- **Version:** 1.0 (Initial Draft)
- **Date:** April 6, 2025
- **Status:** In Progress
- **Document Owner:** Project Team

1.2 Revision History

Version	Date	Description		Author
0.1	March 30, 2025	Initial structure		Fubin Chen
0.5	April 3, 2025	First draft of architecture		Fubin Chen
1.0	April 6, 2025	Completed initiation phase content		Project Team

1.3 Approvals

1.4 Document Purpose

This document defines the system architecture, components, and design specifications for the Smart Maintenance Platform for Aero Engine Industrial Equipment. It serves as the primary reference for development teams and stakeholders throughout the project lifecycle.

1.5 Audience

- Development Team
- Project Stakeholders
- Quality Assurance Team
- Operations Team

1.6 References

- Project Charter (March 29, 2025)
- Requirements Specification (April 3, 2025)
- Risk Management Plan (April 5, 2025)

2. Introduction

2.1 Project Overview

The Smart Maintenance Platform for Aero Engine Industrial Equipment is designed to leverage deep learning technology to enable predictive maintenance for aero engines. By analyzing operational data from sensors and historical maintenance records, the system aims to detect anomalies and predict remaining useful life (RUL) of components, thus enabling maintenance to be performed at optimal times before failures occur.

2.2 System Purpose

The purpose of this system is to:

- Detect anomalies in aero engine operation using advanced deep learning algorithms
- Predict remaining useful life of critical components
- Reduce unplanned downtime through predictive maintenance
- Optimize maintenance scheduling and resource allocation
- Provide comprehensive monitoring and reporting capabilities

2.3 System Scope

The system will encompass:

- Data acquisition from engine sensors
- Data preprocessing and feature engineering
- Anomaly detection using deep learning models
- Remaining useful life prediction
- Web-based user interface for monitoring and analysis
- Alerting and notification system
- Reporting and analytics capabilities

The system is not intended to:

- Replace existing engine control systems
- Directly control engine operations
- Serve as a safety-critical system

2.4 Design Goals and Constraints

2.4.1 Design Goals

- Create a modular and extensible architecture
- Ensure high availability and reliability
- Support real-time monitoring and analysis
- Provide intuitive user interfaces
- Enable integration with existing maintenance systems
- Achieve high prediction accuracy

2.4.2 Design Constraints

- Must operate within the existing IT infrastructure
- Must comply with aviation industry data security standards
- Must handle high-volume sensor data efficiently
- Must support various sensor types and data formats
- Must operate with limited bandwidth in some deployment scenarios

2.5 Assumptions and Dependencies

- Access to historical engine operational data for model training
- Availability of sensor data in near real-time
- Integration capabilities with existing maintenance management systems
- Adequate computational resources for deep learning model inference

3. System Architecture

3.1 Architectural Overview

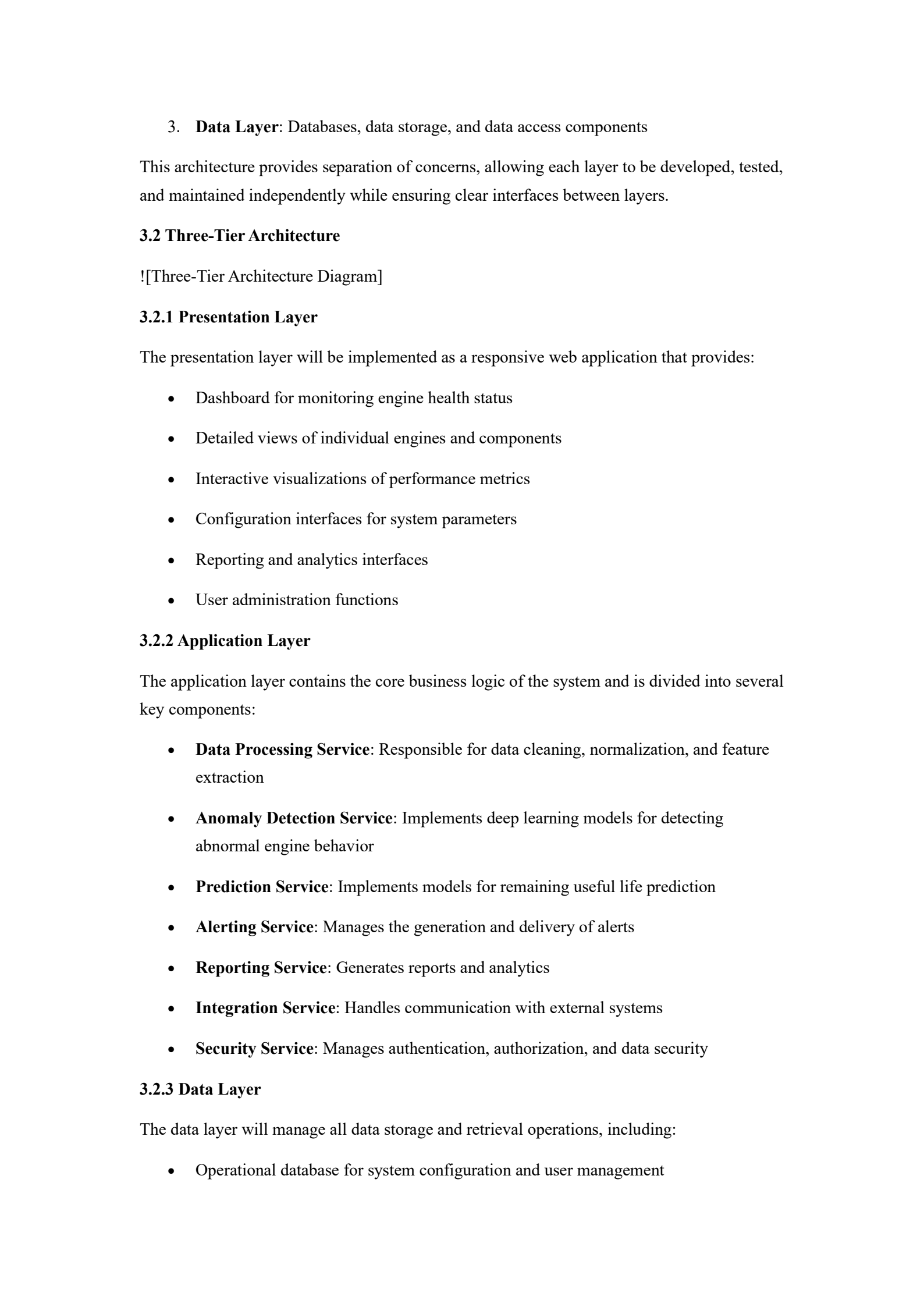
The Smart Maintenance Platform employs a three-tier architecture consisting of:

1. **Presentation Layer**: Web-based user interfaces
2. **Application Layer**: Business logic, data processing, and machine learning models

3. **Data Layer**: Databases, data storage, and data access components

This architecture provides separation of concerns, allowing each layer to be developed, tested, and maintained independently while ensuring clear interfaces between layers.

3.2 Three-Tier Architecture



3.2.1 Presentation Layer

The presentation layer will be implemented as a responsive web application that provides:

- Dashboard for monitoring engine health status
- Detailed views of individual engines and components
- Interactive visualizations of performance metrics
- Configuration interfaces for system parameters
- Reporting and analytics interfaces
- User administration functions

3.2.2 Application Layer

The application layer contains the core business logic of the system and is divided into several key components:

- **Data Processing Service**: Responsible for data cleaning, normalization, and feature extraction
- **Anomaly Detection Service**: Implements deep learning models for detecting abnormal engine behavior
- **Prediction Service**: Implements models for remaining useful life prediction
- **Alerting Service**: Manages the generation and delivery of alerts
- **Reporting Service**: Generates reports and analytics
- **Integration Service**: Handles communication with external systems
- **Security Service**: Manages authentication, authorization, and data security

3.2.3 Data Layer

The data layer will manage all data storage and retrieval operations, including:

- Operational database for system configuration and user management

- Time-series database for sensor data storage
- Model storage for trained machine learning models
- Analytics database for reporting and analysis
- Cache storage for performance optimization

3.3 System Components and Relationships

The system comprises the following major components:

1. **Data Acquisition Module**: Collects data from various sources including sensors, maintenance records, and external systems
2. **Data Processing Module**: Cleans, transforms, and prepares data for analysis
3. **Machine Learning Module**: Houses anomaly detection and prediction models
4. **Visualization Module**: Renders data and insights through user interfaces
5. **Alerting Module**: Monitors system outputs and generates appropriate notifications
6. **API Gateway**: Provides standardized access to system functionality
7. **Authentication & Authorization Module**: Controls access to system resources

These components interact through well-defined interfaces, with data flowing from acquisition through processing and analysis to visualization and alerting.

3.4 Deployment Architecture

[Initial deployment architecture to be developed in next phase]

4. Data Design

4.1 Data Models

[Preliminary data models to be developed in next phase]

4.2 Database Schema Design

[Initial schema design to be completed in next phase]

5. Module Designs

5.1 Device Center Module

5.1.1 Purpose and Functionality

The Device Center Module will serve as the central repository for all engine and component information. It will:

- Maintain a catalog of all monitored engines and components
- Track configuration and specifications for each device
- Record maintenance history and operational parameters
- Provide interfaces for device management operations
- Support device grouping and categorization

5.1.2 Module Components

[To be detailed in next phase]

5.2 Monitoring Center Module

5.2.1 Purpose and Functionality

The Monitoring Center Module will provide real-time and historical monitoring of engine performance. It will:

- Display current operational status of all engines
- Present historical performance trends and patterns
- Highlight anomalies and deviations from normal operation
- Provide drill-down capabilities for detailed analysis
- Support customizable monitoring views and dashboards

5.2.2 Module Components

[To be detailed in next phase]

5.3 Data Simulation Module

5.3.1 Purpose and Functionality

The Data Simulation Module will allow users to simulate engine operation under various conditions. It will:

- Generate synthetic data based on configurable parameters
- Support what-if analysis for different operational scenarios
- Provide a testbed for evaluating potential maintenance strategies
- Allow validation of prediction models without affecting real systems

5.3.2 Module Components

[To be detailed in next phase]

5.4 Alert System Module

5.4.1 Purpose and Functionality

The Alert System Module will notify users of significant events and conditions. It will:

- Monitor system outputs for conditions requiring attention
- Generate alerts based on configurable rules and thresholds
- Deliver notifications through multiple channels (UI, email, SMS)
- Track alert acknowledgment and resolution
- Provide an alert history for audit and analysis

5.4.2 Module Components

[To be detailed in next phase]

5.5 Reporting System Module

5.5.1 Purpose and Functionality

The Reporting System Module will generate insights and analytics from system data. It will:

- Produce standard and custom reports on system operation
- Provide analytics on maintenance effectiveness
- Generate compliance and audit reports
- Support scheduled report generation and distribution
- Enable export of reports in various formats

5.5.2 Module Components

[To be detailed in next phase]

6. Machine Learning Model Design

6.1 Model Selection Rationale

Based on the initial evaluation conducted by Xuanhe Yang, several machine learning approaches have been identified as suitable for the predictive maintenance tasks:

1. **For Anomaly Detection**:
    - Skip-GANomaly: Selected for its ability to effectively model normal

behavior patterns and detect deviations

- PHOT (Phase-Only Transform): Selected for its capability to process frequency domain features

2. **For Remaining Useful Life Prediction**:
    - CNN-LSTM: Selected for combining CNN's spatial feature extraction with LSTM's temporal modeling
    - CNN-Transformer: Selected for capturing long-range dependencies in time series data
    - DBN-BiGRU: Selected for deep feature extraction and bidirectional temporal modeling

These models will be further evaluated and refined in the next phase of the project.

7. User Interface Design

[To be developed in next phase]

8. Interface Specifications

[To be developed in next phase]

9. Non-Functional Design Aspects

[To be developed in next phase]

10. Appendices

10.1 Glossary

- **RUL**: Remaining Useful Life
- **PdM**: Predictive Maintenance
- **CNN**: Convolutional Neural Network
- **LSTM**: Long Short-Term Memory
- **GAN**: Generative Adversarial Network
- **DBN**: Deep Belief Network
- **BiGRU**: Bidirectional Gated Recurrent Unit
- **PHOT**: Phase-Only Transform

10.2 Technical Diagrams

[To be added in next phase]

10.3 Design Decisions Log

Decision	Rationale	Date	Decision Maker
Adopt three-tier architecture	To separate concerns and enable modular development	April 3, 2025	Fubin Chen
Use deep learning for anomaly detection	Superior performance compared to traditional methods	April 4, 2025	Xuanhe Yang
Select CNN-LSTM, CNN-Transformer, and DBN-BiGRU for evaluation	Each offers unique advantages for time series prediction	April 6, 2025	Xuanhe Yang

10.4 References

[To be expanded in next phase]