FAKULTI TEKNOLOGI MAKLUMAT DAN KOMUNIKASI (FTMK)

BITI 3533 AI PROJECT MANAGEMENT

PROJECT REPORT

PROJECT TITLE:

AIRCRAFT PREDICTIVE MAINTENANCE

GROUP MEMBERS:

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TABLE OF CONTENTS

1. Introduction – background and case study

The application of hybrid prediction models, such as Levenberg-Marquardt, Scaled conjugate gradient, Imperialist competitive, Genetic algorithms, etc., is the main focus of creating smart mobility and transportation maintenance systems. Not to be overlooked were the advantages of applying cutting-edge machine learning to road inspection and how hybrid prediction models can enhance transportation maintenance systems. To begin with, you should be aware that advanced machine learning is the process of using intricate statistical models and algorithms to teach machines to learn from data and make predictions or decisions on their own without the need for explicit programming. Among the data that machine learning is used to analyze are weather, traffic volume, and pavement conditions.

In contrast, hybrid prediction models integrate various machine learning algorithms to enhance the precision and dependability of forecasts. For instance, a hybrid mode may analyze data and generate predictions using both genetic algorithms and neural networks. These models have the potential to significantly reduce costs and increase safety in transportation maintenance systems by assisting in the early detection of possible problems.

Our project's main goal is to predict the aircraft engines' remaining useful lives (RUL) by utilizing RNNs. Our goal is to equip airlines with a proactive tool to anticipate potential problems and prevent unplanned breakdowns by utilizing the power of these neural networks. This greatly improves overall aviation safety while saving airlines a significant amount of money.

Our project's predictive maintenance models combine single multi-layer perceptron neural networks with radial basis functions to examine the advantages and benefits of each technique. Our models' hybrid design allows for a thorough comprehension of engine health and performance, providing the aviation industry with a more nuanced viewpoint for maintenance planning and decision-making. Our project aims to introduce advanced neural network architectures to aircraft maintenance procedures, thereby ushering in a new era of safety and efficiency.

2. Detail about the software used

2.1. MATLAB

MATLAB, a powerful numerical computing environment, is the foundation of our predictive aircraft maintenance project. Its extensive feature set and versatility make it an excellent platform for developing and deploying advanced machine-learning models. MATLAB's capabilities in data analysis, visualization, and deep learning, in particular, provide a comprehensive ecosystem for addressing complex problems in aviation safety.

2.2. Deep Learning Toolbox

The Deep Learning Toolbox in MATLAB is critical to our project. This specialized module simplifies the design and implementation of deep neural networks. Because we are focusing on recurrent neural networks (RNNs) for predicting aircraft maintenance needs, this toolbox makes it easier to create, train, and evaluate RNN models. Its support for sequence-to-sequence modeling matches the time-series nature of our predictive maintenance data perfectly.

2.3. Neural Network Toolbox

The Neural Network Toolbox in MATLAB is another essential component of our model development. We can use this toolbox to define the architecture of our RNN, configure layers, and configure training options. Because of the toolbox's versatility, we can work with a variety of neural network architectures, ensuring that our RNN is tailored to the complexities of predictive maintenance scenarios.

2.4. Matlab graph and chart

The powerful visualization tools in MATLAB help us analyze and interpret the results of our machine learning model. These capabilities are used to visualize training progress, inspect predictions, and gain insights into the RNN's behavior. These visualizations are critical to the refinement and optimization of our predictive maintenance solution.

2.5. Python & PyCharm

We use these software tools to analyze the raw data obtained from the sensor, clean it, and divide the data so it can be implemented on our Matlab. This includes removing unnecessary data, normalization, data cleansing, and so on.

3. Detail on AI project management

3.1. Project Overview

As a team, all the members should know and have the same understanding and work momentum to achieve the project's goal at the estimated time. Hence, the project will be successful and all the stakeholders will be happy then expect a new project from the team for a huge investment incoming.

To make it happen, our team must follow the 5-phase project workflow as follows for this particular project:

Phase	**Planning Explanation**
Initiating	• Identify the stakeholders that are willing to make an effort and maybe fund the project to be successful. • Develop a project charter for highlighting the project title, the start and end date for the project, the project manager, the objectives, the approach used, the list of stakeholders with their corresponding responsibilities, and lastly the signages of each stakeholder so the team know that all the stakeholders agree that the project should be taken and proceed.

Planning	● Develop the project management plan by doing the discussion meeting among the members of the organization and including the stakeholders. ● Plan and define the scope management should be catered to build the project. ● Collect all the possible requirements related to the project such as the hardware, software, workers, and resources. ● Create a work breakdown structure for a simple brief overview of the project. ● Plan the schedule management by defining the activities, and the person in charge, then estimating activity resources and durations for each task and subtask involved. ● Plan the project cost by estimating each resource's value and the budget needed to execute the project. ● Plan the project risk management by identifying all the possible positive and negative risks, performing the qualitative and quantitative risk analysis, and building responses for each risk when it happens.
Executing	● Acquire, develop, and manage a suitable project team so each subteam can work together to achieve all the goals as expected. ● Direct and manage all the work that should be done by the workers based on the project planning. ● Perform quality assurance. ● Manage the communication among the team so each member knows all the information and no misunderstanding occurs. ● Manage stakeholder engagement by having a short meeting and briefing them about the project.

Monitoring & Controlling	● Perform integrated change control if there is any change needs to be performed. ● Validate and control the scope so that the project still be on track and does not miss any small detail ahead. ● Control the schedule where the project manager should look after the workers so each of them is still working on the schedule. ● Control the cost so it will not exceed the budget plan. Otherwise, the project will gain no profit and expect a loss. ● Check the quality of the product prototype from time to time so it is still serving the right purposes. ● Control the risks that happen in the middle of the project execution by rapidly taking the actions as planned in the risk planning phase. ● Control the stakeholders' engagement by making a follow-up meeting and informing them about the project's progress from time to time.
Closing	● Close the project of each phase properly by documenting the project working data. This is useful for the team to make the next project more successful, faster to be done, and create bigger projects in the future. ● Deploy or launch the product to the targeted audience/ community to gain benefits.

3.2. Work Breakdown Structure

To wrap all the information about the project deliverables to be more brief and simple to be viewed by all the members of the organisation during the meeting, a work breakdown structure is commonly used as a tool to plan and visualise the project plan in one figure as follows:

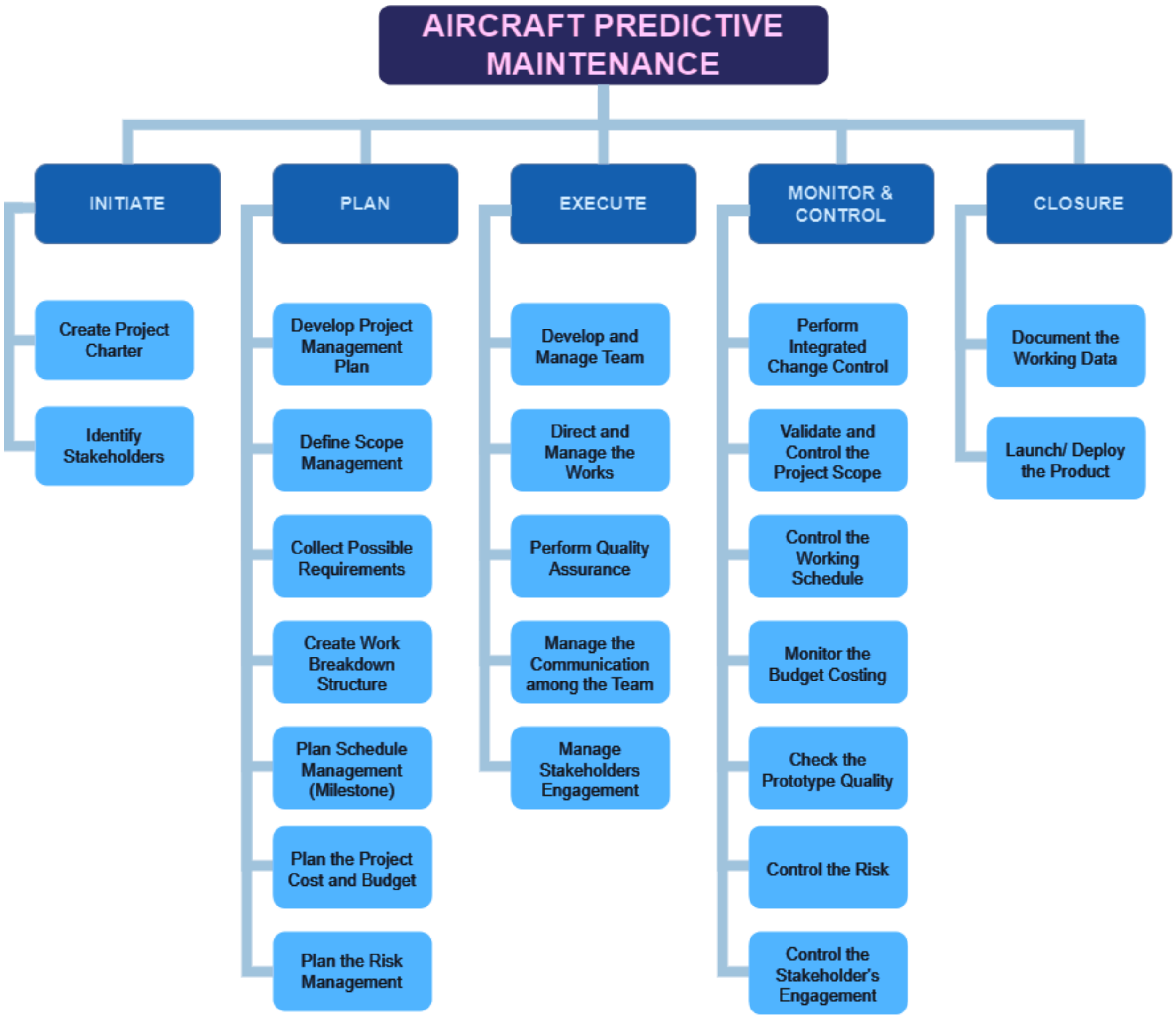

Figure 3.2: Work Breakdown Structure of Aircraft Predictive Maintenance Project

3.3. Project Insight

In every project there are several elements known as knowledge Areas that we have to take into account before, during, and after the project is developed. These knowledge areas will help us to cover all the project insight to develop a quality product with a suitable budget and time taken.

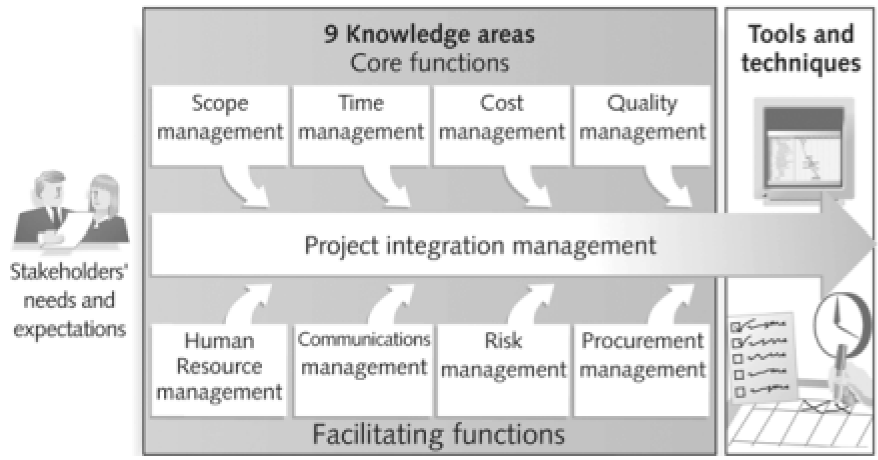

Figure 3.3: The 9 Knowledge Areas of Project Management

Knowledge Areas	Project Management
Integration	● Ensure seamless integration of all project components, including hardware, software, data, and personnel. ● Develop workflow plans and communication channels to facilitate collaboration across teams. ● Monitor and manage interfaces between different project elements to identify and address integration issues. ● Proactively coordinate tasks and activities to ensure overall project coherence and success.
Scope	● Develop and implement a neural network-based APMS

	for predicting aircraft component failures and scheduling preemptive maintenance. ● Define the functionalities and features of the system, including data acquisition, algorithm execution, failure prediction, and maintenance scheduling tools. ● Establish clear boundaries to exclude out-of-scope activities.
Time	● Develop a comprehensive project schedule with defined milestones for each phase (initiating, planning, executing, monitoring and controlling, closing). ● Allocate a realistic timeframe for each task considering dependencies and potential risks. ● Implement effective time management tools and techniques to track progress and identify potential delays. ● Communicate any schedule changes to stakeholders promptly and transparently.
Cost	● Develop a detailed budget outlining all project expenses, including personnel, equipment, software, data acquisition, training, and maintenance. ● Monitor expenses closely and implement cost-saving measures without compromising quality. ● Utilise resource optimization techniques and consider alternative solutions where feasible. ● Regularly report on budget progress and address any variances to stakeholders.
Quality	● Define clear quality standards and key performance indicators (KPIs) for the APMS.

	• Implement rigorous quality control procedures throughout the development and testing phases. • Conduct thorough unit, integration, and system testing to ensure the functionality, performance, and accuracy of the system. • Encourage a culture of continuous improvement and address quality issues promptly.
Human Resources	• Identify and recruit the necessary personnel with skills and expertise relevant to the project. • Develop clear roles and responsibilities for each team member. • Foster a collaborative and open communication environment within the team. • Provide ongoing training and development opportunities to ensure team effectiveness. • Address individual needs and preferences for optimal motivation and performance.
Communication	• Establish clear communication channels and protocols for information sharing across stakeholders (project team, sponsors, airlines, manufacturers). • Regularly communicate project progress, updates, and challenges to stakeholders. • Ensure transparency and open communication to address concerns and feedback effectively. • Utilise appropriate communication tools and formats to cater to different communication styles
Risk	• Proactively identify potential risks that could impact project success (e.g., data quality, algorithm accuracy,

	technological advancements). ● Analyse the likelihood and impact of each risk and develop mitigation strategies. ● Continuously monitor for risk emergence and adjust mitigation plans as needed. ● Communicate identified risks and mitigation strategies to relevant stakeholders.
Procurement	● Identify and select vendors for essential resources and services (e.g., data providers, hardware, software). ● Develop clear and concise procurement plans and contracts outlining expectations and deliverables. ● Maintain effective communication with vendors and manage dependencies during project execution. ● Ensure ethical and responsible procurement practices throughout the project.
Stakeholders	● Identify and engage all key stakeholders involved in the project (e.g., management, sponsors, users, regulatory bodies). ● Understand their needs, expectations, and concerns regarding the project. ● Actively involve stakeholders in key decision-making processes when appropriate. ● Manage stakeholder expectations throughout the project lifecycle and address concerns promptly.

4. Flow, algorithm, and problem-solving

4.1. Flowchart

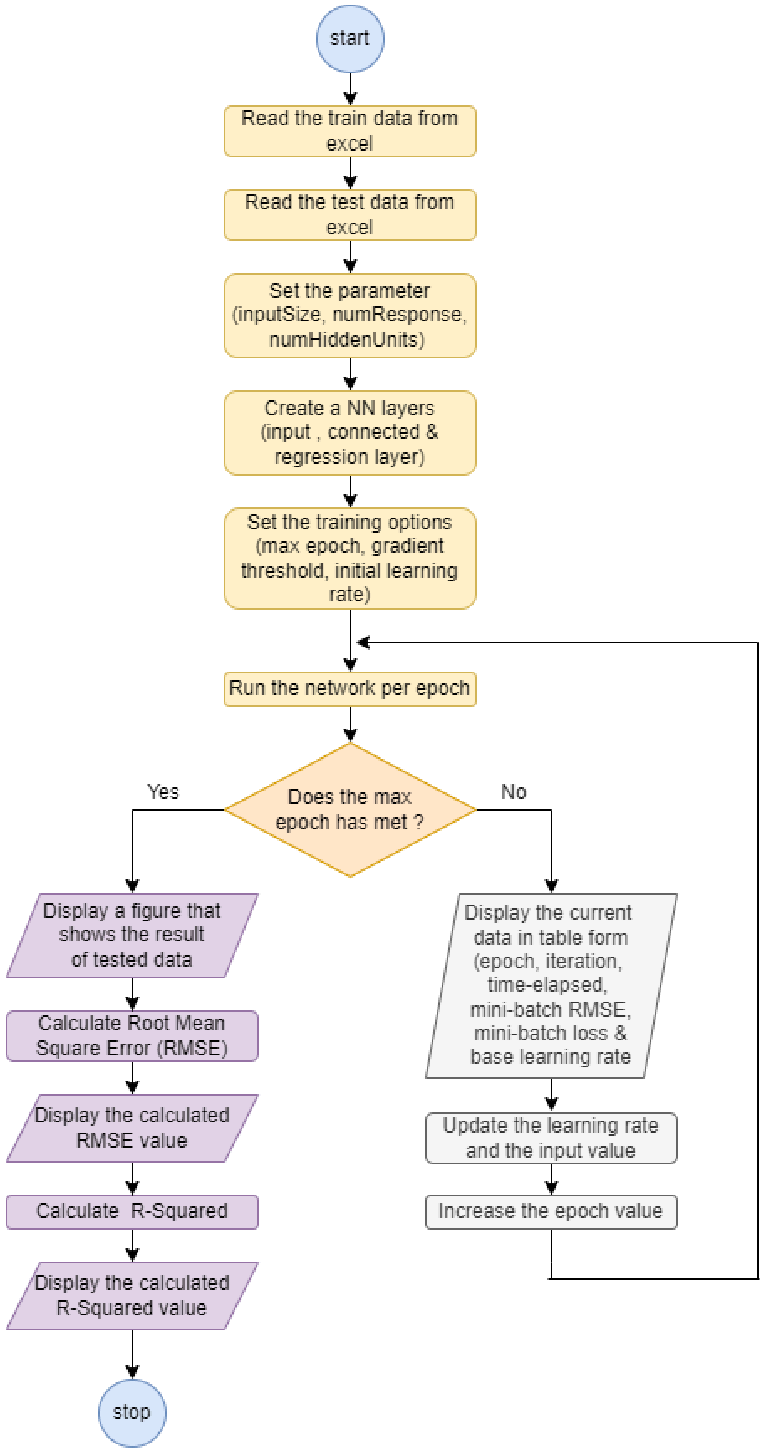

Figure 4.1: Flowchart on how the APM System works

Our analysis of Aircraft Predictive Maintenance consists of several important steps to get the best result about the machine's condition whether it is in good condition or near failure. All the explained steps refer to Figure 1 below:

1. Read the train data from Excel that has a total of 1388 data from columns A - Z
2. Read the test data from Excel also consists of 1388 data in column AA
3. Set the parameter which is input size = 1388 similar to the number of data inside the Excel, number of responses = 1388, and number of hidden units/layers = 100.
4. Create a neural network layering based on the fixed value assigned to each parameter so there is a platform for the data to go through the RNNs process.
5. Set the training options which are max epoch = 1000, gradient threshold = 0.01 and the initial learning = 0.0001.
6. While the max epoch = 1000 has not been met (start with epoch number 1):
    - 6.1. Display the current data in table form (epoch, iteration, time-elapsed, mini-batch RMSE, mini-batch loss & base learning rate). We can observe whether the data is getting better or not.
    - 6.2. Update the learning rate and the input value based on the particular computed data.
    - 6.3. Increase the epoch value so that the program can iterate the process.
    - 6.4. If the max epoch has been met, terminate the looping and go to the next process.

7. Display a figure that shows the result of tested data. From this figure, we can see the accuracy of predictive maintenance was conducted in a whole process by displaying the predicted values compared to the exact values.
8. Calculate Root Mean Square Error (RMSE) to observe that the value we got from the entire process is a high error value or a low error value.
9. Display the calculated RMSE value on the console.
10. Calculate R-squared to let us know how accurate the value resulted from the prediction program.
11. Display the calculated R-squared value

4.2. Algorithm

Our project uses recurrent neural networks (RNNs) for predictive maintenance of aircraft engines. RNNs can be used to forecast the remaining usable life (RUL) of aircraft engines, which can help avoid unanticipated breakdowns and increase safety while saving airlines money. The models include single multi-layer perceptron and radial basis function neural networks as well as their hybrids.

Long short-term memory (LSTM) algorithms are being used in the learning and analysis process of this project. LSTM is a type of RNN that learns by being trained on a dataset of labeled data. The Data is presented to the LSTM in a sequence, and the LSTM learns to predict the next element in the sequence. For this case study, the data that is used in LSTM is the ID, Settings, and Sensors from the data sets of aircraft engines.

4.3. Problem-solving

By using the LSTM technique, the problems in aircraft predictive maintenance can be solved efficiently. It can be used to forecast the remaining usable life (RUL) of aircraft engines which allows maintenance teams to proactively schedule interventions before components fail, help identify components nearing the end of their life, minimize unnecessary replacements and reduce maintenance costs, detect engines at risk of failure that contributing to improved safety and preventing potential accidents, and optimize maintenance schedules based on predictive insights, minimizing downtime and maximizing the operational efficiency of aircraft fleets.

Other than that, the project also helps in the continuous improvement of the aircraft industry. It helps establish a feedback loop with maintenance teams to incorporate real-world insights to maintain the aircraft engine and continuously refine the predictive maintenance models to help the model adapt to evolving patterns, ensuring that the system remains effective over time.

5. Project implementation and output

5.1. Data Collection and Preprocessing

Sources of data for this project have been collected by companies that have worked in the industry and through other sources, Cleaning and preprocessing data is a fundamental step in preparing it for analysis or machine learning. The process involves several key steps to ensure the data is accurate, consistent, and ready for further exploration.

Upon collecting the data from various sources, it's essential to conduct an initial exploratory data analysis (EDA) to understand the dataset's structure, size, and basic statistics. During this exploration, potential issues such as missing values, outliers, and inconsistencies should be identified. Handling missing values is a critical aspect of data preprocessing. Missing values can be addressed by either removing rows or columns, imputing values using statistical measures, or employing machine learning-based imputation methods. The chosen strategy should be implemented, and the changes made documented for transparency.

Challenges that are faced require a combination of domain knowledge, data exploration techniques, and careful decision-making during the preprocessing steps.

5.2. Feature Selection

Feature engineering is a critical aspect of enhancing the predictive power of models in the context of aircraft predictive maintenance. Several techniques can be applied to create new, informative features that capture the nuances of the data and contribute to the accuracy of the predictions. One key approach involves incorporating time-based features. Rolling statistics, such as rolling averages or sums, calculated over specific time windows, can capture trends and variations in maintenance-related features over time. Additionally, some of the features that are considered to be included in this project are historical averages, domain-specific features, and Incorporating failure history. These features contain great value in assisting our predictive power.

5.3. Machine Learning Algorithms

The choice of RNNs with STM and LSTMs for your project is well-founded given the temporal nature of aircraft maintenance data. These algorithms excel in capturing patterns in sequential data, which is essential when predicting maintenance events that unfold over time.

Additionally, these algorithms may require substantial computational resources for training, and hyperparameter tuning can be a complex task. Ensuring the appropriate balance between model complexity and generalization capacity is crucial, as overly complex models may lead to overfitting, especially when dealing with limited data.

Furthermore, the interpretability of neural network models, including RNNs and LSTMs, can be a trade-off. Understanding the internal workings of these models may be challenging, making it essential to weigh the benefits of predictive accuracy against the interpretability of the results.

5.4. Model Training and Evaluation

In the model training and evaluation phase, the process begins with the extraction of data from Excel files. The training data, consisting of 1388 entries spanning columns A to Z, is read, along with the test data located in column AA. The model parameters are set, configuring the input size to match the number of data points (1388), the number of responses also set to 1388, and the number of hidden units or layers fixed at 100. This establishes the foundation for the subsequent Recurrent Neural Networks (RNNs) process.

The neural network layering is created based on the specified parameter values, providing a structured platform for the data to undergo the RNNs process. Training options are set, defining the maximum number of epochs as 1000, a gradient threshold of 0.01, and an initial learning rate of 0.0001. The training process iterates through epochs, each time displaying key information such as epoch number, iteration, elapsed time, mini-batch Root Mean Square Error (RMSE), mini-batch loss, and the base learning rate. This real-time feedback allows observation of the model's performance and whether improvements are occurring.

During each epoch iteration, the learning rate and input values are updated based on the computed data. The epoch value is increased, allowing the program to iterate through the training process. If the maximum epoch limit of 1000 is met, the looping terminates, transitioning to the next phase.

Upon completion of training, a figure is displayed showcasing the results of the tested data. This visualization provides insights into the accuracy of predictive maintenance by comparing predicted values to the exact values. Subsequently, the Root Mean Square Error (RMSE) is calculated, offering a quantitative measure of the model's predictive performance. The calculated RMSE value is displayed on the console, allowing for an assessment of the error magnitude.

Furthermore, R-squared, an indicator of the accuracy of the prediction program, is computed. The calculated R-squared value is displayed, providing additional insight into the predictive capabilities of the model. Overall, this comprehensive training and evaluation process ensures a thorough assessment of the model's performance in predicting maintenance events, aiding in decision-making for aircraft maintenance strategies.

5.5. Integration with Aircraft Systems

Integrating with aircraft systems can be a challenging task but we believe that integrating it will be much help to the system and aircraft industry. Not only, the system assists in predicting maintenance which leads to cost savings by minimising the need for emergency repairs and unscheduled maintenance With the ability to plan and schedule maintenance activities strategically, airlines can optimise the use of resources, reduce overtime costs, and lower the overall operational costs associated with reactive maintenance practices.

Furthermore integrating our project into the aircraft system can also lead to even more dependent data which will be able to enhance our predictive power. Operational efficiency is enhanced by streamlining maintenance workflows. Airlines can systematically plan maintenance activities, aligning them with operational schedules to minimize disruptions. This leads to smoother operations, improved on-time performance, and better overall service reliability.

5.6. Real-Time Monitoring

Real-time monitoring in the predictive maintenance system is a critical component that ensures timely detection and response to evolving conditions. This section outlines the mechanisms for real-time monitoring, continuous data updates, model retraining, and the communication of maintenance predictions to personnel.

Implementing real-time monitoring enhances the system even more because The system relies on a continuous data update mechanism to ensure that the model remains informed about the latest sensor readings, maintenance logs, and relevant operational data instead of needing to update the data constantly. Next,

adapting to changing patterns and conditions, the model undergoes periodic retraining based on continuous data updates. Retraining intervals are determined by the system's configuration and can be triggered by predefined events such as a significant change in operational conditions or a set time interval.

Furthermore, Maintenance predictions are communicated to personnel in real-time through a user interface that provides intuitive visualizations and actionable insights. Relevant charts and graphs, such as predicted maintenance events, confidence intervals, and remaining useful life estimates, are displayed dynamically.

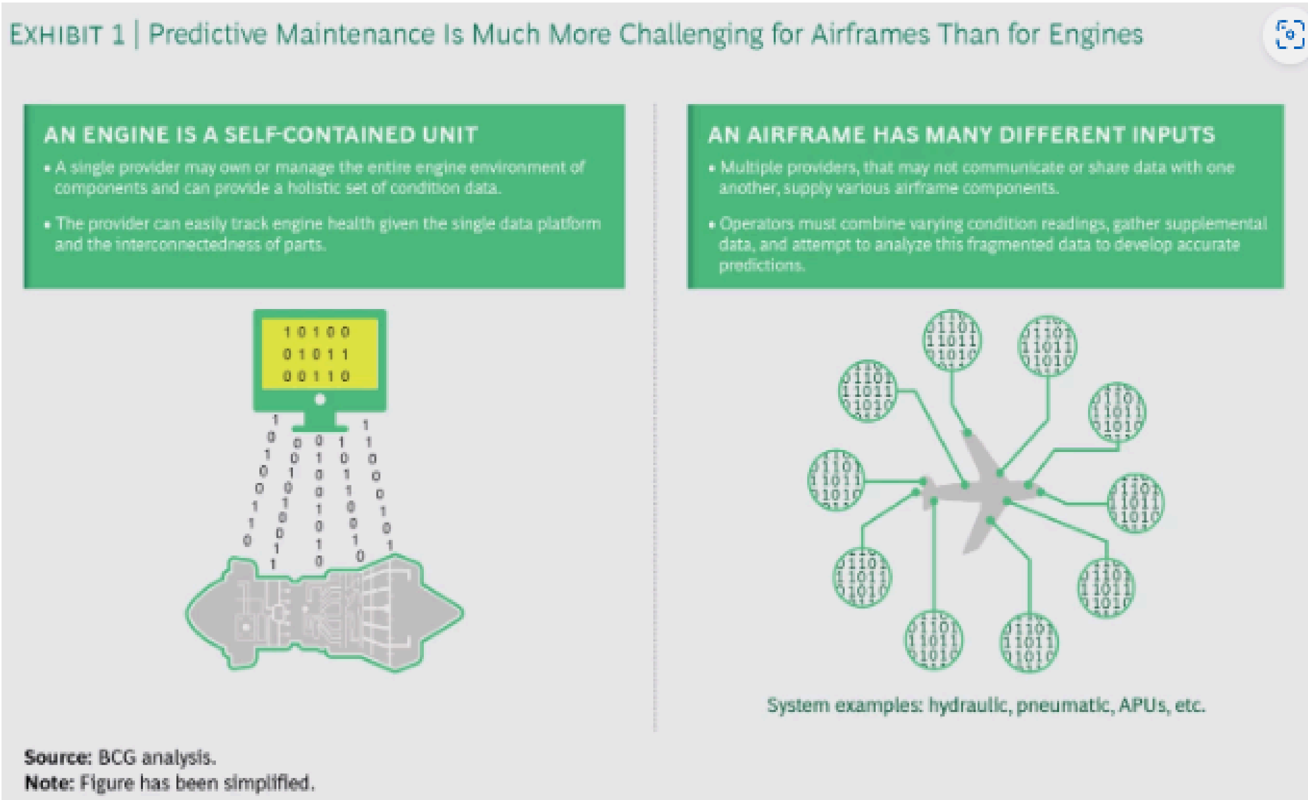

Figure 5.1: Different parts of aircraft that apply the system

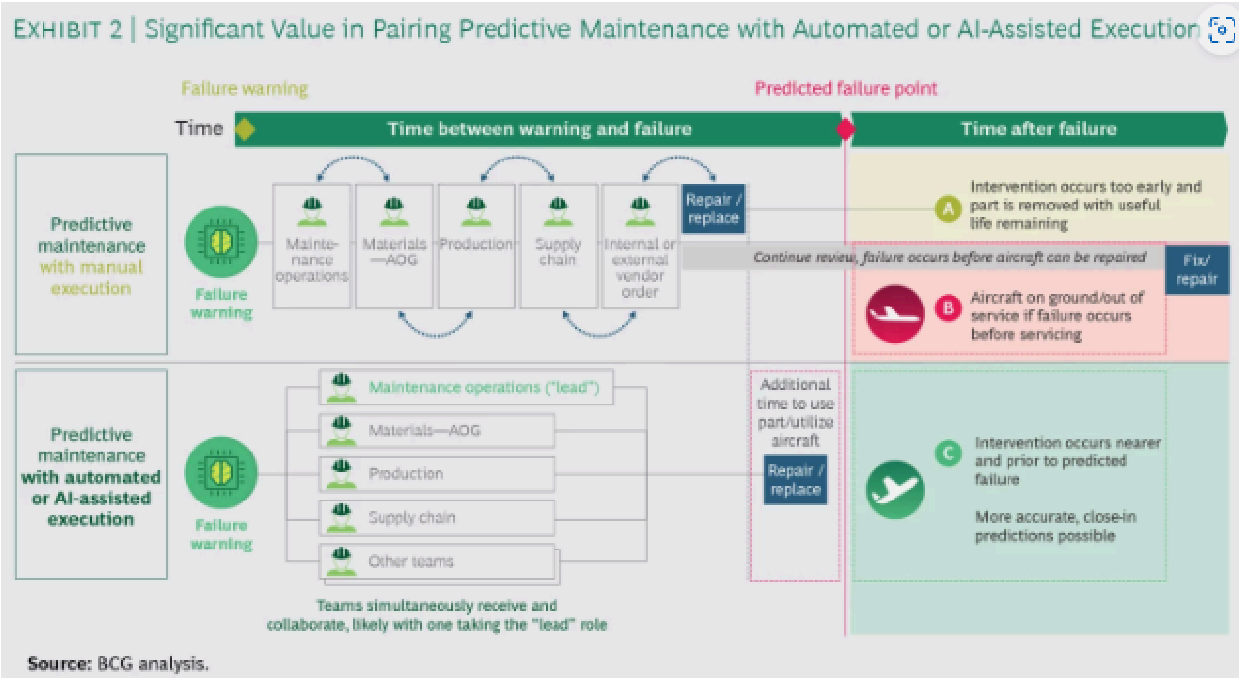

Figure 5.2: Significant value in pairing predictive maintenance with AI

EXHIBIT 3 | Where We Are—and Where We Need to Be—with Predictive MRO in Aviation

	CURRENT STATE	NEEDED STATE
Engineering validation	• Predictions validated or rejected by an engineer through manual compilation, review, and analysis of corroborating data	• Predictions routed to engineering in real time and queued by urgency rather than first-in, first-out • Validation largely automated by assembling historical removal and repair data on a serial- and part-number basis
Mid-term planning	• Maintenance planner queues validated removal prediction into planned maintenance • Planner annually generates a task to replace the affected component	• Validated removal prediction assigned to an optimized RON date and location based on operating schedule, manpower capacity, material availability, and station capability
Material requisition	• Supply chain generates a tools and materials forecast based on queue of short-term planned maintenance and queries the inventory system	• Material and tooling requirements defined in the authorized task are pushed to the inventory system • In-stock materials are flagged for shipment to the recommended maintenance location, with approval of logistics team
Procurement	• Depending on availability, supply chain issues a PO for the needed tools and materials	• Material and tooling requirements defined in the authorized task are pushed to the procurement system • Out-of-stock material with required delivery-by date is ordered and shipped from approved vendors
Short-term planning	• A short-term maintenance planner manually monitors the prediction deadline and, with OCC, assigns task to a maintenance location	• Prediction status is visible to a short-term maintenance planner with changes in risk highlighted in an alert system • Planner intervenes only to reassign the associated task to a date and maintenance location if needed
Aircraft routing	• OCC operator routes the aircraft to the chosen maintenance location in advance, manually coordinates	• Additional time and automatic routing allow aircraft to fly more of its schedule and have part replaced at scheduled maintenance location
Material handling	• Supply chain orders tools and materials and sends to the chosen maintenance location, if necessary	• Supplies are ordered based on collective team decision • Materials are automatically routed to aircraft based on revised schedule
Maintenance provider	• Receives aircraft with tight turnaround time and limited context on repair needs	• Full case file provided in advance with parts and tools prepared

Source: BCG analysis.

Figure 5.3: Overview of the current and desired state of predictive maintenance

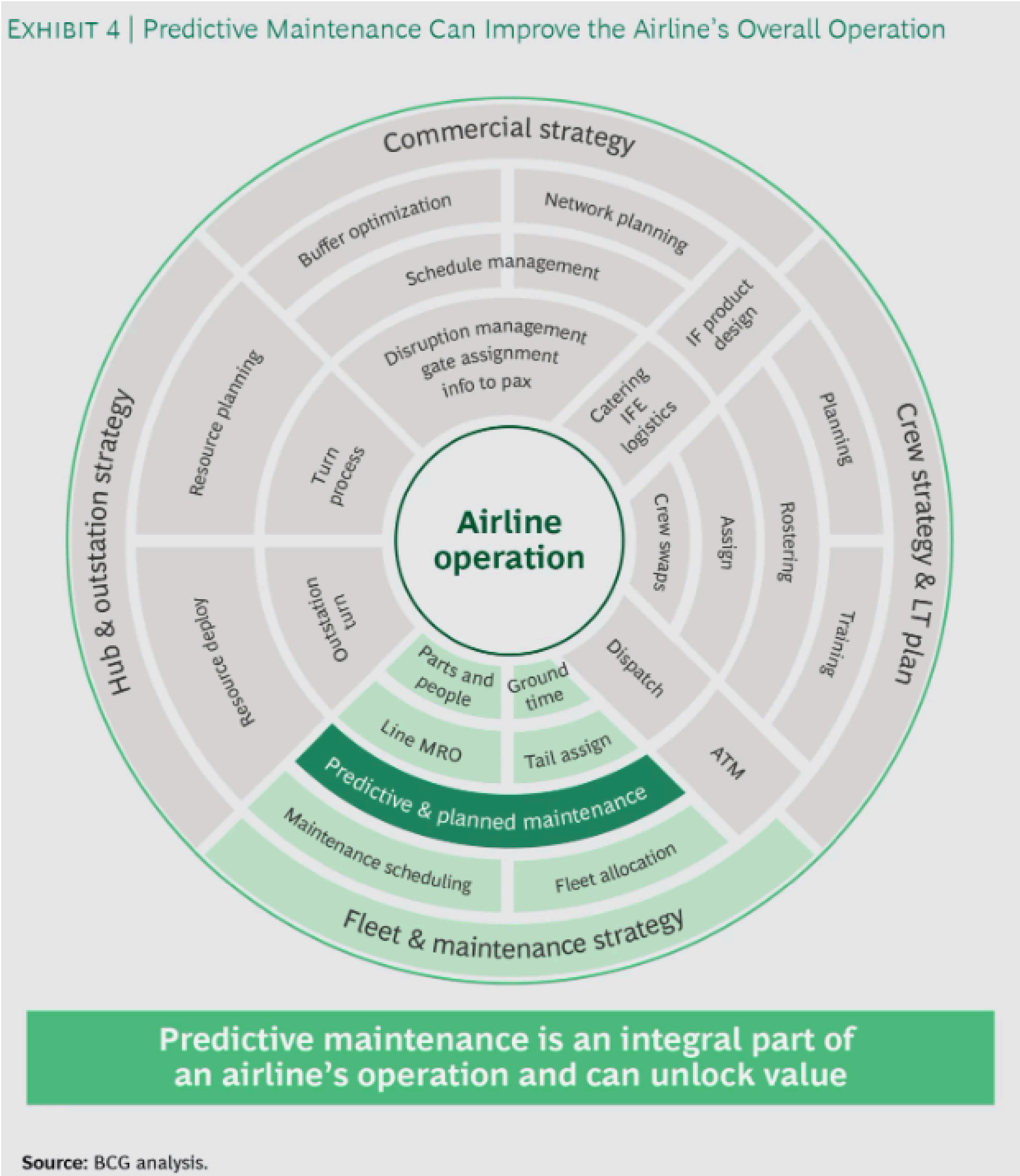

Figure 5.4: Integral part of an airline's operation

6. Conclusion

In conclusion, the adoption of predictive aircraft maintenance signifies a transformative leap forward in the aviation industry's approach to ensuring the safety, reliability, and cost-effectiveness of its fleets. The integration of advanced data analytics and machine learning algorithms empowers airlines to shift from reactive to proactive maintenance strategies, ushering in an era where potential issues are identified and addressed before they can impact operations.

This paradigm shift not only enhances safety by mitigating the risk of in-flight malfunctions but also optimizes operational efficiency, minimizes downtime, and contributes to substantial cost savings. The remaining usable lifespan (RUL) of aircraft components, achieved through proactive measures, aligns with sustainable asset management practices. The reliance on data-driven decision-making ensures that airlines can make informed choices about maintenance activities, leading to more effective and strategic operations.

While challenges such as data security and model interpretability must be considered, the ongoing evolution of technology and collaborative efforts between data scientists and aviation professionals promise a future where predictive maintenance continues to drive innovation, making aviation safer, more reliable, and economically sustainable.

7. References

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8. Appendices

With the help of machine learning techniques such as multi-layer perceptron and radial basis function neural networks were used for data analysis. Furthermore, with the given test data below we tested the data using MATLAB application and we gained this data from Kagell in a .xls file format so that it is easier for our team to read the data through the app.

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13	Column14	Column15	Column16	Column17	Column18	Column19	Column20	Column21	Column22	Column23	Column24	Column25	Column26	Column27
1	1	-0.0007	-0.0004	100	518.67	641.82	1589.7	1400.6	14.62	21.61	554.36	2388.06	9046.19	1.3	47.47	521.66	2388.02	8138.62	8.4195	0.03	392	2388	100	39.06	23.419	112
1	2	0.0019	-0.0003	100	518.67	642.15	1591.82	1403.14	14.62	21.61	553.75	2388.04	9044.07	1.3	47.49	522.28	2388.07	8131.49	8.4318	0.03	392	2388	100	39	23.4236	112
1	3	-0.0043	0.0003	100	518.67	642.35	1587.99	1404.2	14.62	21.61	554.26	2388.08	9052.94	1.3	47.27	522.42	2388.03	8133.23	8.4178	0.03	390	2388	100	38.95	23.3442	112
1	4	0.0007	0	100	518.67	642.35	1582.79	1401.87	14.62	21.61	554.45	2388.11	9049.48	1.3	47.13	522.86	2388.08	8133.83	8.3682	0.03	392	2388	100	38.88	23.3739	112
1	5	-0.0019	-0.0002	100	518.67	642.37	1582.85	1406.22	14.62	21.61	554	2388.06	9055.15	1.3	47.28	522.19	2388.04	8133.8	8.4294	0.03	393	2388	100	38.9	23.4044	112
1	6	-0.0043	-0.0001	100	518.67	642.1	1584.47	1398.37	14.62	21.61	554.67	2388.02	9049.68	1.3	47.16	521.68	2388.03	8132.85	8.4108	0.03	391	2388	100	38.98	23.3669	112
1	7	0.001	0.0001	100	518.67	642.48	1592.32	1397.77	14.62	21.61	554.34	2388.02	9059.13	1.3	47.36	522.32	2388.03	8132.32	8.3974	0.03	392	2388	100	39.1	23.3774	112
1	8	-0.0034	0.0003	100	518.67	642.56	1582.96	1400.97	14.62	21.61	553.85	2388	9040.8	1.3	47.24	522.47	2388.03	8131.07	8.4076	0.03	391	2388	100	38.97	23.3106	112
1	9	0.0008	0.0001	100	518.67	642.12	1590.98	1394.8	14.62	21.61	553.69	2388.05	9046.46	1.3	47.29	521.79	2388.05	8125.69	8.3728	0.03	392	2388	100	39.05	23.4066	112
1	10	-0.0033	0.0001	100	518.67	641.71	1591.24	1400.46	14.62	21.61	553.59	2388.05	9051.7	1.3	47.03	521.79	2388.06	8129.38	8.4286	0.03	393	2388	100	38.95	23.4694	112
1	11	0.0018	-0.0003	100	518.67	642.28	1581.75	1400.64	14.62	21.61	554.54	2388.05	9049.61	1.3	47.15	521.4	2388.01	8140.58	8.434	0.03	392	2388	100	38.94	23.4787	112
1	12	0.0016	0.0002	100	518.67	642.06	1583.41	1400.15	14.62	21.61	554.52	2388.09	9049.37	1.3	47.18	521.8	2388.02	8134.25	8.3938	0.03	391	2388	100	39.06	23.366	112
1	13	-0.0019	0.0004	100	518.67	643.07	1582.19	1400.83	14.62	21.61	553.44	2388.12	9046.82	1.3	47.38	521.85	2388.08	8128.1	8.4152	0.03	393	2388	100	38.93	23.2757	112
1	14	0.0009	0	100	518.67	642.35	1592.95	1399.16	14.62	21.61	554.48	2388.09	9047.37	1.3	47.44	521.67	2388	8134.43	8.3964	0.03	393	2388	100	39.18	23.3826	112
1	15	-0.0018	-0.0003	100	518.67	642.43	1583.82	1402.13	14.62	21.61	553.64	2388.11	9052.22	1.3	47.3	522.5	2388.08	8127.56	8.4199	0.03	391	2388	100	38.99	23.35	112
1	16	0.0006	0.0005	100	518.67	642.13	1587.98	1404.5	14.62	21.61	553.94	2388.05	9049.34	1.3	47.24	521.49	2388.07	8136.11	8.3936	0.03	392	2388	100	38.97	23.455	112
1	17	0.0002	0.0002	100	518.67	642.58	1584.96	1399.95	14.62	21.61	553.8	2388.06	9054.92	1.3	47.12	521.89	2388.04	8137.27	8.4542	0.03	392	2388	100	38.81	23.3319	112
1	18	-0.0031	-0.0001	100	518.67	642.62	1591.04	1396.12	14.62	21.61	554.2	2388.05	9049.55	1.3	47.21	521.76	2388.07	8132.73	8.4028	0.03	392	2388	100	38.89	23.3987	112
1	19	0.0032	-0.0003	100	518.67	641.79	1587.56	1400.35	14.62	21.61	554.18	2388.04	9053.99	1.3	47.4	521.89	2388.03	8129.13	8.4321	0.03	391	2388	100	38.8	23.3464	112
1	20	-0.0037	0.0001	100	518.67	643.04	1581.11	1405.23	14.62	21.61	554.81	2388.05	9045.9	1.3	47.22	522.07	2388.02	8129.71	8.421	0.03	392	2388	100	39.03	23.422	112
1	21	-0.0012	0.0001	100	518.67	642.37	1586.07	1398.13	14.62	21.61	554.08	2388.11	9048.15	1.3	47.15	522.42	2388.08	8134.02	8.4049	0.03	392	2388	100	39.09	23.3101	112
1	22	0.0002	0	100	518.67	642.77	1592.93	1400.57	14.62	21.61	553.63	2388.04	9061.21	1.3	47.24	522	2388.03	8130.41	8.4034	0.03	392	2388	100	38.92	23.3792	112
1	23	0.0034	-0.0003	100	518.67	642.14	1588.19	1394.75	14.62	21.61	553.98	2388.05	9046.28	1.3	47.25	521.52	2388.05	8127.9	8.424	0.03	392	2388	100	38.94	23.4562	112
1	24	-0.001	0.0003	100	518.67	642.38	1590.83	1398.81	14.62	21.61	553.49	2388.12	9043.76	1.3	47.44	522.13	2388.03	8133.88	8.3891	0.03	392	2388	100	39	23.3696	112
1	25	0.0023	-0.0004	100	518.67	642.77	1594.1	1399.39	14.62	21.61	554	2388.02	9054.16	1.3	47.36	522.56	2388.02	8136.61	8.3917	0.03	393	2388	100	38.95	23.4288	112
1	26	0	0.0002	100	518.67	642.16	1589.08	1396.07	14.62	21.61	554.11	2388.07	9047.11	1.3	47.26	522.28	2388.06	8131.15	8.426	0.03	394	2388	100	38.86	23.4149	112
1	27	-0.0012	-0.0004	100	518.67	642.44	1590.47	1401.84	14.62	21.61	554.07	2388.02	9047.96	1.3	47.37	522	2388.13	8134.6	8.4046	0.03	393	2388	100	38.99	23.4472	112
1	28	-0.0024	0.0005	100	518.67	642.35	1582.84	1399.13	14.62	21.61	554.68	2388.12	9049.84	1.3	47.41	522.57	2388.08	8127.3	8.4323	0.03	390	2388	100	39.01	23.2841	112
1	29	0.0012	-0.0001	100	518.67	641.91	1584.83	1400.99	14.62	21.61	554.25	2388.05	9050.47	1.3	47.24	522.41	2388.06	8133.06	8.4189	0.03	393	2388	100	38.93	23.3597	112
1	30	-0.0022	0	100	518.67	642.2	1593.52	1396.08	14.62	21.61	554.37	2388.07	9045.62	1.3	47.4	522.19	2388	8137.86	8.4065	0.03	390	2388	100	39.05	23.411	112
1	31	0.0014	0.0005	100	518.67	642.02	1584.18	1396.9	14.62	21.61	554.13	2388.08	9058.78	1.3	47.41	521.95	2388.06	8125.28	8.4104	0.03	392	2388	100	38.94	23.3353	112
1	32	0.0005	-0.0003	100	518.67	642.33	1591.38	1400.36	14.62	21.61	554.96	2388.04	9050.97	1.3	47.25	521.92	2388.07	8129.7	8.4148	0.03	392	2388	100	39.02	23.4999	112
1	33	-0.0042	-0.0004	100	518.67	642.71	1588.4	1402.43	14.62	21.61	554.61	2388.04	9047.13	1.3	47.28	521.91	2388.08	8134.42	8.3753	0.03	392	2388	100	38.83	23.3506	112
1	34	0.0015	-0.0001	100	518.67	642.54	1581.47	1400.48	14.62	21.61	554.3	2388.03	9046.46	1.3	47.47	521.7	2388.09	8126.61	8.4349	0.03	392	2388	100	38.81	23.3092	112
1	35	0.0003	0.0002	100	518.67	642.44	1590	1403	14.62	21.61	554.3	2388.04	9045.76	1.3	47.31	521.75	2388.01	8140.17	8.443	0.03	391	2388	100	39.13	23.4164	112
1	36	-0.0004	-0.0002	100	518.67	642.54	1581.72	1405.54	14.62	21.61	554.53	2388.01	9044.56	1.3	47.25	522.32	2388.04	8132.48	8.4246	0.03	392	2388	100	38.86	23.4308	112
1	37	-0.0004	0	100	518.67	641.99	1579.11	1398.9	14.62	21.61	554.63	2388.07	9055.44	1.3	47.29	522.29	2388.04	8131.95	8.4142	0.03	392	2388	100	38.99	23.4352	112

Table 1: Training Data of an Aircraft

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1	Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13	Column14	Column15	Column16	Column17	Column18	Column19	Column20	Column21	Column22	Column23	Column24	Column25	Column26	Column27
2	1	1	0.0023	0.0003	100	518.67	643.02	1585.29	1398.21	14.62	21.61	553.9	2388.04	9050.17	1.3	47.2	521.72	2388.03	8125.55	8.4052	0.03	392	2388	100	38.86	23.3735	112
3	1	2	-0.0027	-0.0003	100	518.67	641.71	1588.45	1395.42	14.62	21.61	554.85	2388.01	9054.42	1.3	47.5	522.16	2388.06	8139.62	8.3803	0.03	393	2388	100	39.02	23.3916	112
4	1	3	0.0003	0.0001	100	518.67	642.46	1586.94	1401.34	14.62	21.61	554.11	2388.05	9056.96	1.3	47.5	521.97	2388.03	8130.1	8.4441	0.03	393	2388	100	39.08	23.4166	112
5	1	4	0.0042	0	100	518.67	642.44	1584.12	1406.42	14.62	21.61	554.07	2388.03	9045.29	1.3	47.28	521.38	2388.05	8132.9	8.3917	0.03	391	2388	100	39	23.3737	112
6	1	5	0.0014	0	100	518.67	642.51	1587.19	1401.92	14.62	21.61	554.16	2388.01	9044.55	1.3	47.31	522.15	2388.03	8129.54	8.4031	0.03	390	2388	100	38.99	23.413	112
7	1	6	0.0012	0.0003	100	518.67	642.11	1579.12	1395.13	14.62	21.61	554.22	2388	9050.96	1.3	47.26	521.92	2388.08	8127.46	8.4238	0.03	392	2388	100	38.91	23.3467	112
8	1	7	0	0.0002	100	518.67	642.11	1583.34	1404.84	14.62	21.61	553.89	2388.05	9051.39	1.3	47.31	522.01	2388.06	8134.97	8.3914	0.03	391	2388	100	38.85	23.3952	112
9	1	8	0.0006	0	100	518.67	642.54	1580.89	1400.89	14.62	21.61	553.59	2388.05	9052.86	1.3	47.21	522.09	2388.06	8125.93	8.4213	0.03	393	2388	100	39.05	23.3224	112
10	1	9	-0.0036	0	100	518.67	641.88	1593.29	1412.28	14.62	21.61	554.49	2388.06	9048.55	1.3	47.37	522.03	2388.05	8134.15	8.4353	0.03	391	2388	100	39.1	23.4521	112
11	1	10	-0.0025	-0.0001	100	518.67	642.07	1585.25	1398.64	14.62	21.61	554.28	2388.04	9051.95	1.3	47.14	522	2388.06	8134.08	8.4093	0.03	391	2388	100	38.87	23.382	112
12	1	11	0.0007	-0.0004	100	518.67	642.04	1581.03	1403.83	14.62	21.61	554.69	2388.04	9051.67	1.3	47.23	521.95	2388.06	8132.38	8.3919	0.03	391	2388	100	39.06	23.3609	112
13	1	12	0.0026	0.0003	100	518.67	642.54	1587.43	1397.82	14.62	21.61	554.35	2388.02	9050.02	1.3	47.27	522.01	2388.06	8132.33	8.3984	0.03	391	2388	100	39.11	23.3845	112
14	1	13	-0.0056	0.0003	100	518.67	641.94	1589.09	1403.94	14.62	21.61	554.04	2388.02	9045.67	1.3	47.35	522.37	2388.03	8131.12	8.4166	0.03	392	2388	100	39.08	23.3677	112
15	1	14	0.0017	-0.0004	100	518.67	642.23	1583.16	1402.88	14.62	21.61	554.66	2388.03	9045.3	1.3	47.24	521.95	2388.06	8130.3	8.4293	0.03	392	2388	100	39.03	23.4572	112
16	1	15	-0.0003	-0.0003	100	518.67	642.5	1584.81	1398.79	14.62	21.61	554.15	2388	9052.59	1.3	47.35	521.38	2388	8133.62	8.4163	0.03	392	2388	100	39.04	23.3672	112
17	1	16	-0.0018	0.0003	100	518.67	642.32	1584.51	1407.76	14.62	21.61	553.82	2388.1	9041.94	1.3	47.39	522.16	2388.1	8133.83	8.43	0.03	390	2388	100	38.87	23.3484	112
18	1	17	0.0014	0.0002	100	518.67	642.19	1582.7	1404.12	14.62	21.61	554.42	2388.06	9045.85	1.3	47.27	522.09	2388.02	8126.78	8.4577	0.03	391	2388	100	39.09	23.3409	112
19	1	18	0.0035	0.0001	100	518.67	642.59	1586.53	1403.69	14.62	21.61	553.5	2388.04	9048.12	1.3	47.44	522.14	2388.06	8133.22	8.4323	0.03	391	2388	100	38.96	23.4481	112
20	1	19	0.0029	0.0001	100	518.67	642.43	1585.58	1402.3	14.62	21.61	553.87	2388.01	9046.9	1.3	47.25	522.06	2388.01	8129.31	8.3892	0.03	391	2388	100	39.06	23.3809	112
21	1	20	0.0011	-0.0001	100	518.67	642.61	1587.78	1400.7	14.62	21.61	554.31	2388.05	9041.12	1.3	47.46	522.28	2388.05	8128.59	8.4099	0.03	392	2388	100	39	23.3325	112
22	1	21	0.0038	-0.0002	100	518.67	642.7	1583.3	1399.2	14.62	21.61	554.42	2388.05	9053.73	1.3	47.36	522.05	2388.11	8126.86	8.4174	0.03	392	2388	100	38.96	23.4025	112
23	1	22	0.0012	0.0001	100	518.67	642.45	1582.78	1404.06	14.62	21.61	553.43	2388	9046.45	1.3	47.26	521.41	2388.04	8128.89	8.4557	0.03	392	2388	100	38.94	23.377	112
24	1	23	0.0009	0	100	518.67	642.12	1587.51	1395.09	14.62	21.61	555.07	2388.04	9052.06	1.3	47.19	522	2388.06	8130.97	8.4116	0.03	393	2388	100	39.1	23.3186	112
25	1	24	-0.0006	-0.0001	100	518.67	642.32	1594.29	1400.15	14.62	21.61	553.27	2388.07	9043.32	1.3	47.29	522.06	2388.12	8130.7	8.4074	0.03	393	2388	100	38.94	23.3971	112
26	1	25	0.0028	-0.0003	100	518.67	642.25	1582.43	1400.23	14.62	21.61	553.76	2388.11	9043.8	1.3	47.37	522.26	2388.08	8128.65	8.4007	0.03	393	2388	100	38.96	23.3785	112
27	1	26	0.0047	-0.0005	100	518.67	642.48	1583.28	1408.07	14.62	21.61	554.59	2388.08	9053.43	1.3	47.33	521.95	2388.07	8129.12	8.3949	0.03	391	2388	100	38.77	23.3557	112
28	1	27	-0.0007	0.0001	100	518.67	642.08	1586.65	1400.31	14.62	21.61	554.35	2388.09	9046.1	1.3	47.34	521.82	2388.02	8127.24	8.4494	0.03	392	2388	100	38.87	23.3931	112
29	1	28	0.0022	0.0005	100	518.67	641.93	1594.25	1401.29	14.62	21.61	553.56	2388.07	9055.56	1.3	47.05	521.84	2388.07	8134.89	8.447	0.03	392	2388	100	38.83	23.3502	112
30	1	29	0.0014	0.0001	100	518.67	641.95	1587.15	1398.11	14.62	21.61	554.15	2388.08	9046.11	1.3	47.42	522.39	2388.07	8133.13	8.4212	0.03	392	2388	100	39.02	23.3621	112
31	1	30	-0.0025	0.0004	100	518.67	642.79	1585.72	1400.97	14.62	21.61	554.1	2388.09	9047.45	1.3	47.4	521.78	2388.1	8134.79	8.411	0.03	391	2388	100	39.09	23.4069	112
32	1	31	-0.0006	0.0004	100	518.67	642.58	1581.22	1398.91	14.62	21.61	554.42	2388.08	9056.4	1.3	47.23	521.79	2388.06	8130.11	8.4024	0.03	393	2388	100	38.81	23.3552	112
33	2	1	-0.0009	0.0004	100	518.67	642.66	1589.3	1407.16	14.62	21.61	553.14	2388.1	9040.2	1.3	47.43	521.62	2388.14	8129.59	8.4283	0.03	392	2388	100	39	23.3923	98
34	2	2	-0.0011	0.0002	100	518.67	642.51	1588.43	1405.47	14.62	21.61	553.53	2388.07	9053.77	1.3	47.45	522.02	2388.08	8120.05	8.4414	0.03	393	2388	100	38.84	23.2902	98
35	2	3	0.0002	0.0003	100	518.67	642.58	1595.6	1410.86	14.62	21.61	553.34	2388.13	9036.57	1.3	47.45	521.29	2388.08	8126.75	8.3804	0.03	394	2388	100	39.02	23.4064	98
36	2	4	0.0025	0.0001	100	518.67	642.31	1583.43	1408.23	14.62	21.61	554.15	2388.14	9047.06	1.3	47.42	521.57	2388.06	8129.91	8.4342	0.03	393	2388	100	38.82	23.4699	98
37	2	5	0.0004	-0.0004	100	518.67	642.77	1585.03	1407.6	14.62	21.61	553.98	2388.13	9043.96	1.3	47.47	521.59	2388.11	8127.01	8.4247	0.03	392	2388	100	38.81	23.3895	98
38	2	6	-0.0008	-0.0003	100	518.67	642.5	1579.87	1402.27	14.62	21.61	553.79	2388.11	9042.51	1.3	47.6	521.8	2388.06	8128.82	8.4182	0.03	392	2388	100	38.78	23.2688	98

Table 2: Testing Data of an Aircraft

After the training and testing data has been stored, the system will run to the next process which is creating the neural network layer and start computing and learning the data until the looping is terminated (the max epoch is reached).

Epoch	Iteration	Time Elapsed (hh:mm:ss)	Mini-batch RMSE	Mini-batch Loss	Base Learning Rate
1	1	00:00:00	138555.31	9.6e+09	0.0010
50	50	00:00:03	4950.80	1.2e+07	0.0010
100	100	00:00:05	5356.71	1.4e+07	0.0010
150	150	00:00:08	4377.58	9.6e+06	0.0010
200	200	00:00:11	5135.45	1.3e+07	0.0010
250	250	00:00:13	5002.14	1.3e+07	0.0010
300	300	00:00:16	4248.62	9.0e+06	0.0010
350	350	00:00:19	4524.31	1.0e+07	0.0010
400	400	00:00:21	4914.72	1.2e+07	0.0010
450	450	00:00:24	4215.81	8.9e+06	0.0010
500	500	00:00:27	4488.79	1.0e+07	0.0010
550	550	00:00:30	4700.49	1.1e+07	0.0010
600	600	00:00:32	3793.77	7.2e+06	0.0010
650	650	00:00:35	5231.74	1.4e+07	0.0010
700	700	00:00:38	4450.20	9.9e+06	0.0010
750	750	00:00:40	4465.75	1.0e+07	0.0010
800	800	00:00:43	5281.76	1.4e+07	0.0010
850	850	00:00:45	4856.97	1.2e+07	0.0010
900	900	00:00:48	4630.56	1.1e+07	0.0010
950	950	00:00:51	6708.13	2.2e+07	0.0010
1000	1000	00:00:53	4284.98	9.2e+06	0.0010

Training finished: Max epochs completed.

Figure 8.1: Sample data results in a table form for each 50 iterations

Then, the entire processed data will be generated into a line chart as below:

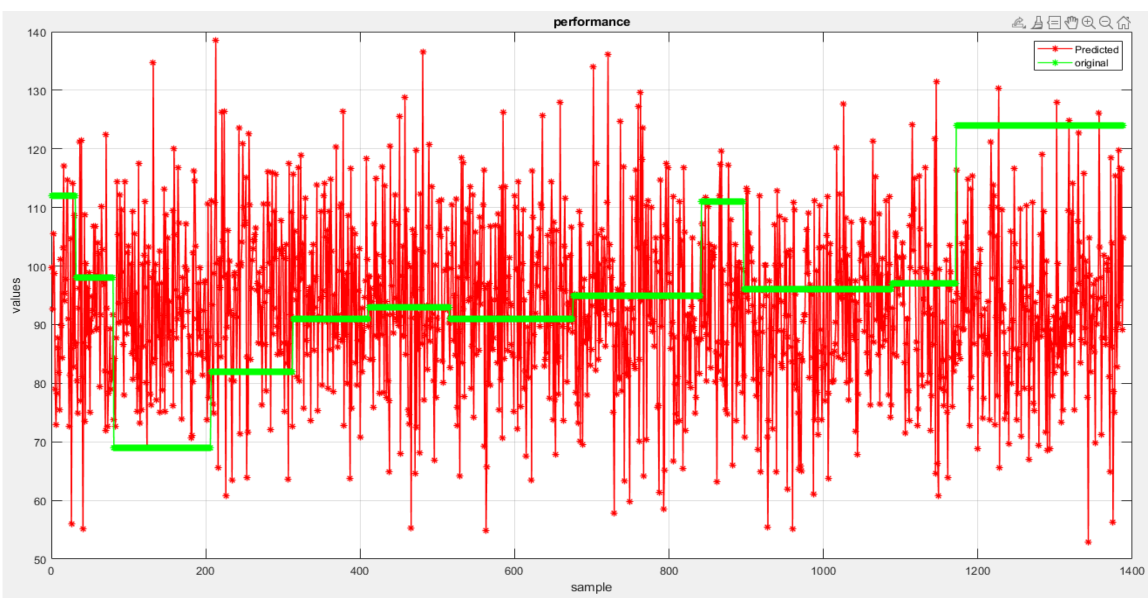

Figure 3: The line chart of predicted and exact value comparison