<u>Project Documentation Report</u>

Project Name : Machine Learning-Based Predictive Analytics for Aircraft Engine

Team ID : PNT2022TMID27252

<u>Team Members :</u>

- Karthikeyan P[Team Lead]
- Krishna Varshan S
- Kavya K
- Kanishkar R

Project Report Format

1. **INTRODUCTION**
    1. Project Overview
    2. Purpose
2. **LITERATURE SURVEY**
    1. Existing problem
    2. References
    3. Problem Statement Definition
3. **IDEATION & PROPOSED SOLUTION**
    1. Empathy Map Canvas
    2. Ideation & Brainstorming
    3. Proposed Solution
    4. Problem Solution fit
4. **REQUIREMENT ANALYSIS**
    1. Functional requirement
    2. Non-Functional requirements
5. **PROJECT DESIGN**
    1. Data Flow Diagrams
    2. Solution & Technical Architecture
    3. User Stories
6. **PROJECT PLANNING & SCHEDULING**
    1. Sprint Planning & Estimation
    2. Sprint Delivery Schedule
    3. Reports from JIRA
7. **CODING & SOLUTIONING (Explain the features added in the project along with code)**
    1. Feature 1
    2. Feature 2
    3. Database Schema (if Applicable)
8. **TESTING**
    1. Test Cases
    2. User Acceptance Testing
9. **RESULTS**
    1. Performance Metrics
10. **ADVANTAGES & DISADVANTAGES**
11. **CONCLUSION**
12. **FUTURE SCOPE**
13. **APPENDIX**

Source Code
GitHub & Project Demo Link

1.INTRODUCTION

1.1 Project Overview

Unexpected failure leads to loss of money and time. Predicting the failure prior will save time, effort, money and sometimes even lives. The failure can be detected by installing the sensors and keeping a track of the values. The failure detection and predictive maintenance can be for any device, out of Engine failure is highly risky and needs a lot of time for repair. which we will be dealing with the engine failure for a threshold number of days.

1.2 Purpose

The project aims to predict the failure of an engine by using Machine Learning to save loss of time & money thus improving productivity.

2. LITERATURE SURVEY

TITLE	FailurePredictionofAircraftEquipmentUsingMachineLearningwitha HybridData PreparationMethod
AUTHORS	KadirCelikmih,OnurInan,andHarunUguz
YEAROFPUBLICATION	12January2020
ABSTRACT	Reliabilityandavailabilityof aircraftcomponentshavealwaysbeenanimportantconsiderationinaviation. Accurate prediction of possible failures will increase thereliability of aircraft components and systems.)eschedulingofmaintenanceoperationshelpdeterminetheoverall maintenance and overhaul costs of aircraftcomponents. Maintenance costs constitute a significantportion of the total operating expenditure of aircraftsystems.
METHODOLOGY	DataMining
MERITS	Accuracy - 0.9316 while using LR and SVR,Comparingmultiplemodelstoselectthebest.
DEMERITS	Consume more time using ReliefF and K - means in datapreparation.
OVERCOMEDEMERITS	Manuallydeletethefieldswhicharelesscontributed.
LINK	https://pdfs.semanticscholar.org/1462/685c83d65bc9d99d9227c435e8035a902e7b.pdf

TITLE	AircraftEngineRemainingUsefulLifePredictionFramew orkforIndustry.
AUTHORS	HusseinA.Taha,AhmedH.Sakr,SoumayaYacout.
YEAROFPUBLICATION	October23-25,2019
ABSTRACT	The proposed model considers continuous learning andimprovementtoaccountfor anyfurtheroperationalchanges that affectthe model prediction ability.This isreachedbyingestingthemodelwiththeactualRULduringthe maintenanceoftheengineunit,andbycomparingittothepredict ed one.
METHODOLOGY	DataAnalysisandDataMining
MERITS	Accuracy-94% Comparingmultiplealgorithms.
DEMERITS	NeedmoreDownTime.
OVERCOMEDEMERITS	UseViewwhichcontainsdatastoredbeforetraining,whic h leads to use the bw system while training anddowntimerequired.
LINK	https://www.researchgate.net/publication/337311736_Aircraft_Engine_Remaining_Useful_Life_Prediction_Framework_for_Industry_40

TITLE	Predictive Maintenance of Aircraft EngineusingDeepLearningTechnique.
AUTHORS	AdePitraHermawan,Dong-SeongKim, Jae-MinLee.
YEAROFPUBLICATION	21December 2020
ABSTRACT	In this paper, an accurate algorithm to estimate remaininguseful life of aircraft engine is proposed. Since the aircraftengine has a low fault tolerant, meaning that a little faulty inthe system can lead to catastrophic conditions, an accurateandreal-timeinformationabouttheengineconditionisrequired. This paper utilizes the combination of CNN andLSTM algorithms in learning the behavior of the historicaldataandprovidingtheaccurateinformationaboutthe timetofailureofthesystem.Thesimulationresultsdemonstrate thattheproposedsystemisabletoachieveimprovedperformance in terms of accuracy rate and computing timecomparedtothepreviousworks.
METHODOLOGY	MachineLearning
MERITS	UsingDeeplearningIncreasestheAccuracyandcomputingtime.
DEMERITS	Didn’tcomparemanyalgorithmtogetthebest.
OVERCOMEDEMERITS	Comparemoremodelswiththesamedata.
LINK	https://ieeexplore.ieee.org/document/9289466/authors#authors

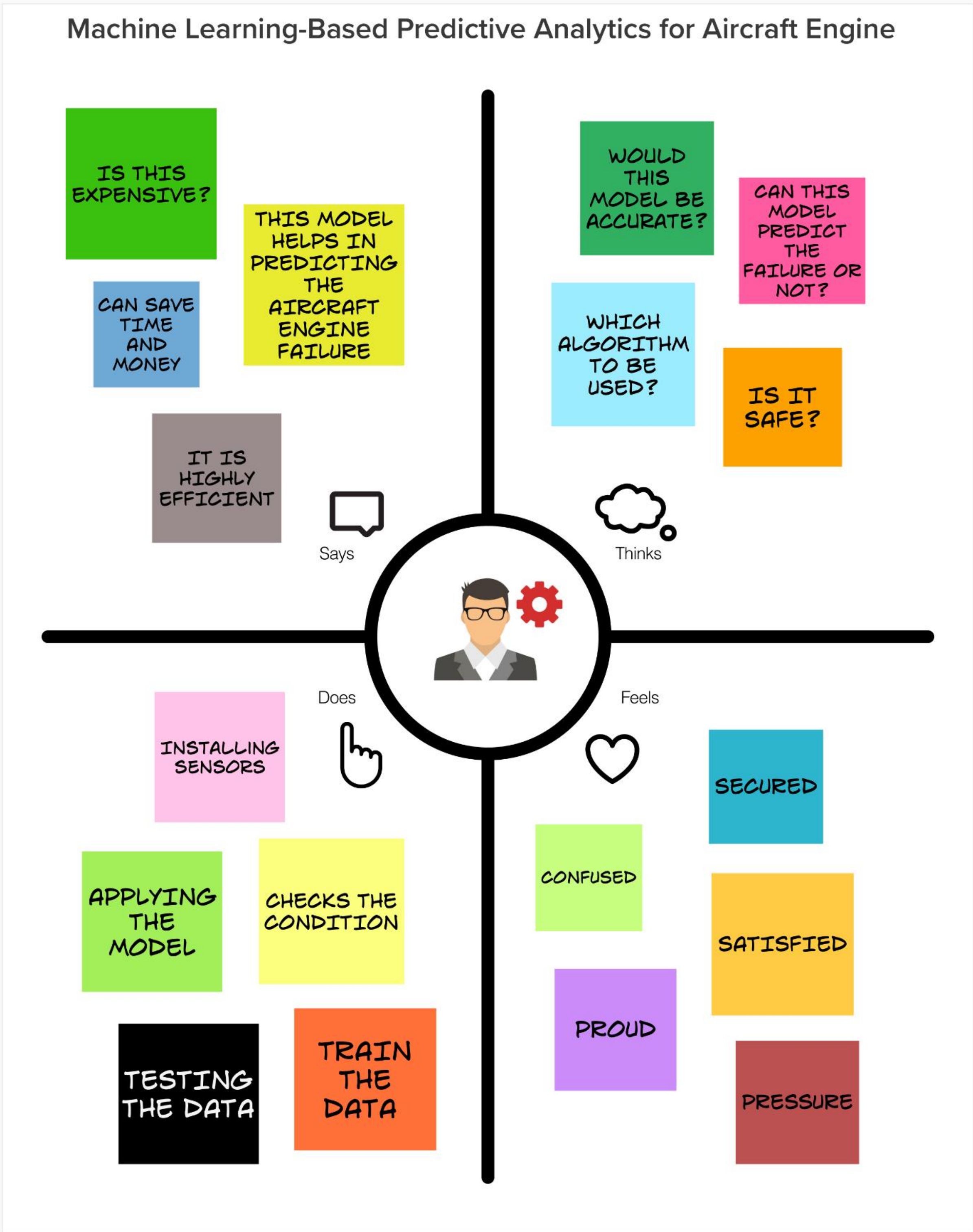
TITLE	Ararefailuredetectionmodelforaircraftpredictivemaintenanceusingadeephybridlearning approach.
AUTHORS	**MarenDavidDangut,IanK.Jennions,SteveKing&ZakwanSkaf**.
YEAROFPUBLICATION	**Published:26March2022**
ABSTRACT	Theuseofaircraftoperationlogstodevelopadata-drivenmodeltopredict probable failures that could cause interruption poses manychallenges and has yet to be fully explored. Given that aircraft ishigh-integrityassets,failuresareexceedinglyrare.Hence,thedistributionofrelevantlogdatacontainingpriorsignswillbeheavily skewed towards the typical (healthy) scenario. Thus, thisstudy presents a novel deep learning technique based on the auto-encoder and bidirectional gated recurrent unit networks to handleextremelyrarefailurepredictionsinaircraftpredictivemaintenance modelling. The auto-encoder is modified and trainedto detect rare failures, and the result from the auto-encoder is fedintotheconvolutionalbidirectionalgatedrecurrentunitnetworktopredictthenextoccurrenceoffailure.
METHODOLOGY	MachineLearningandIOT
MERITS	HighAccuracy,goodrecallandG-means.
DEMERITS	Didn’tcomparemanyalgorithmtogetthebest.
OVERCOMEDEMERITS	Comparemoremodelswiththesamedata.

LINK	https://link.springer.com/article/10.1007/s00521-022-07167-8

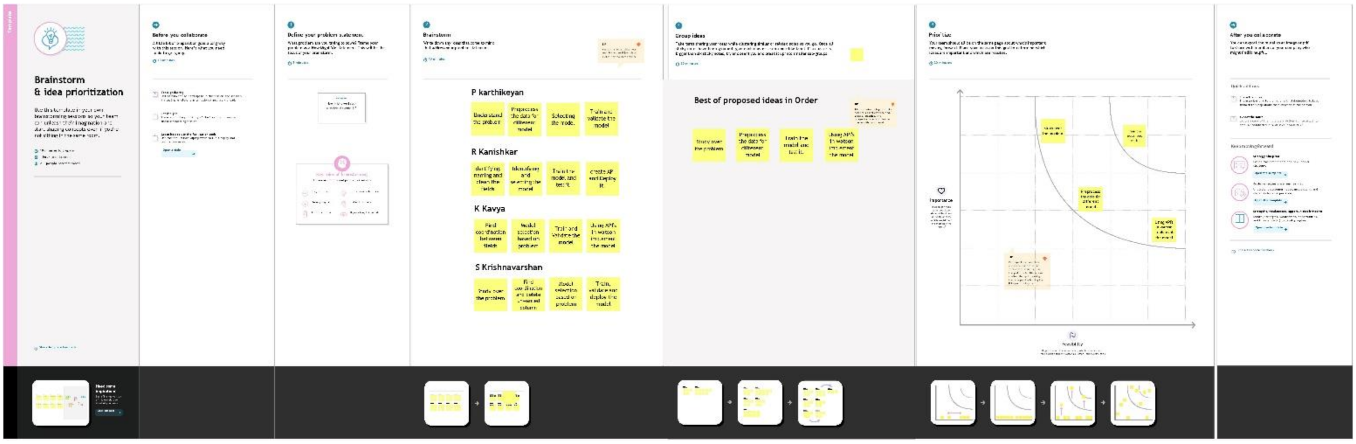
TITLE	PredictiveMaintenanceoftheAircraftEngineBleedAirSystemComponent
AUTHORS	SavithaRamasamy,YangXue,RoystonPhoon, Richard Han, Nelson Low andCheeSiangLim.
YEAROFPUBLICATION	September2018.
ABSTRACT	Thispaperpresentsapredictivemaintenancesolutionofanaircraftenginebleedairsystemcomponentusing machine learning approaches on aircraft QuickAccess Recorder (QAR)data.However,whentheQARparametersare not sufficiently representative of the component health,it has been highlighted that there is a need to leverage onmore data sources such as Smart Access Recorder (SAR)data.
METHODOLOGY	AnalysisandClassification
MERITS	GoodAccuracyinbothtrainingandValidatingdataset.
DEMERITS	Usingonlyone algorithm.
OVERCOMEDEMERITS	Comparemoremodelswiththesamedata.
LINK	https://www.researchgate.net/publication/330357379_Predictive_Maintenance_of_the_Aircraft_Engine_Bleed_Air_System_Component

3. IDEATION & PROPOSED SOLUTION

3.1 Empathy Map Canvas



3.2 Ideation & Brainstorming



3.3 Proposed Solution

Abstraction:

A failure in the aircraft engine tends to a huge loss of life and money. There is a need to analyse the condition of Aircraft engine and detect the failure period of it before it happens, which helps in reducing the accident of aircraft due to engine failure. Different aircraft engine uses different settings in each fly. So, there is a task to analyse the data from different sensors with different settings periodically. The idea of this project is to choose a ML model, train & validate it, deploy it with an API with user friendly UI.

Novelty:

In this project the idea is to increase the training speed of the model by recognizing the impactful factors which affect the target field. And to increase the accuracy of the model in the new set of data. Choosing different Time Series algorithm and compare all those to get the best accuracy and performance. The main freshness in the project is:

• Increasing Accuracy,

• Getting better prediction as using time series algorithm,

• Optimized API to get the predictions easily.

Feasibility of Project:

Every aircraft is different from each other in terms of sensor, engine and settings of it. One of the aims of the project is to build the model which is suitable for most of the aircraft engine. The data going to use in the project need to has data of settings, sensors of different aircrafts engine over the time, which may help in designing the model to work better in different aircraft.

Business Model:

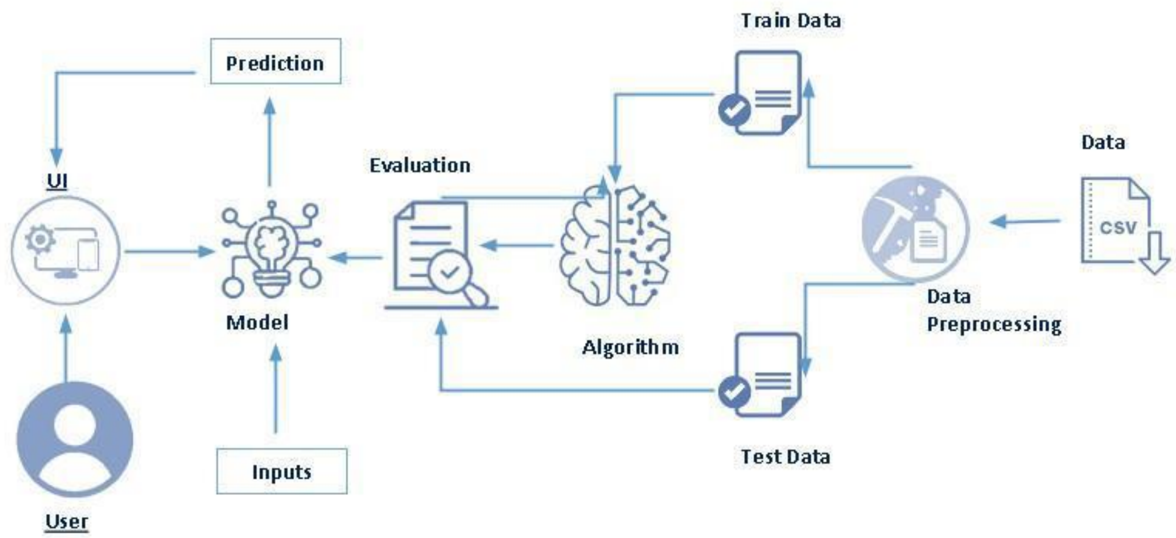
The approach reduces man power which involved in testing the engine each time. It helps in identifying the engine failure or engine maximum cycles before each time of fly. It helps in saving more time and money. And importantly saves more life. It almost reduces 60% of over all process of formal procedures involved in inspecting the aircraft engine.

Social Impact:

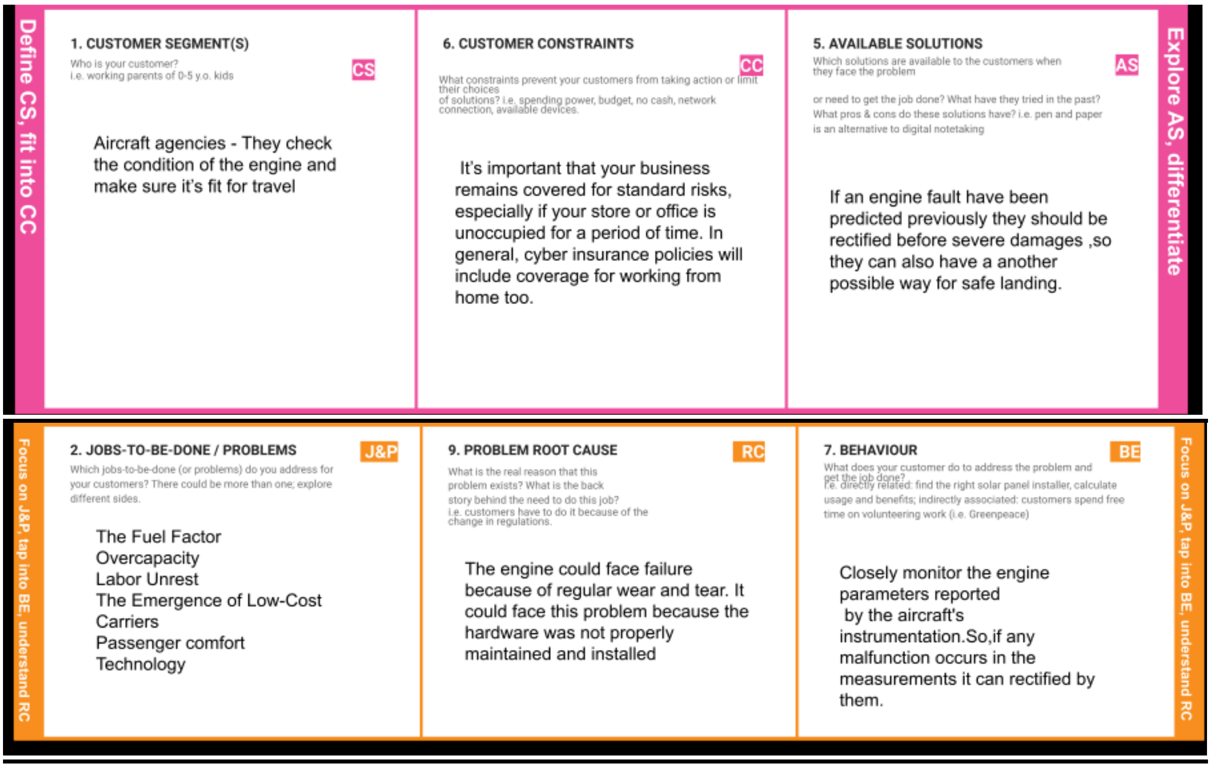
Society wise the project ensure lot of people life who trust the aircraft. As it provides the cycles an aircraft engine can fly helps in schedule the aircraft service early and provide it without any delay. It helps the passengers to reach the destination on time without any delay.

Proposed architecture:

Extract the Data, Pre-process the data for the model, train the data with different algorithm, validate and select the best algorithm, create a API and connect it with the trained model, then connect it with a user friendly UI to get and show the input and result.



3.4 Problem Solution fit



Define CS, fit into CC

1. CUSTOMER SEGMENT(S)

CS

Who is your customer?
i.e. working parents of 0-5 y.o. kids

Aircraft agencies - They check the condition of the engine and make sure it's fit for travel

6. CUSTOMER CONSTRAINTS

CC

What constraints prevent your customers from taking action or limit their choices of solutions? i.e. spending power, budget, no cash, network connection, available devices.

It's important that your business remains covered for standard risks, especially if your store or office is unoccupied for a period of time. In general, cyber insurance policies will include coverage for working from home too.

5. AVAILABLE SOLUTIONS

AS

Which solutions are available to the customers when they face the problem or need to get the job done? What have they tried in the past? What pros & cons do these solutions have? i.e. pen and paper is an alternative to digital notetaking

If an engine fault have been predicted previously they should be rectified before severe damages ,so they can also have a another possible way for safe landing.

Explore AS, differentiate

Focus on J&P, tap into BE, understand RC

2. JOBS-TO-BE-DONE / PROBLEMS

J&P

Which jobs-to-be-done (or problems) do you address for your customers? There could be more than one; explore different sides.

The Fuel Factor
Overcapacity
Labor Unrest
The Emergence of Low-Cost Carriers
Passenger comfort
Technology

9. PROBLEM ROOT CAUSE

RC

What is the real reason that this problem exists? What is the back story behind the need to do this job? i.e. customers have to do it because of the change in regulations.

The engine could face failure because of regular wear and tear. It could face this problem because the hardware was not properly maintained and installed

7. BEHAVIOUR

BE

What does your customer do to address the problem and get the job done? i.e. directly related: find the right solar panel installer, calculate usage and benefits; indirectly associated: customers spend free time on volunteering work (i.e. Greenpeace)

Closely monitor the engine parameters reported by the aircraft's instrumentation.So,if any malfunction occurs in the measurements it can rectified by them.

Focus on J&P, tap into BE, understand RC

3. TRIGGERS

TR

What triggers customers to act? i.e. seeing their neighbor installing solar panels, reading about a more efficient solution in the news.

The passengers complain about

- Baggage theft
- Delayed flights
- Uncomfortable seats

4. EMOTIONS: BEFORE / AFTER

EM

How do customers feel when they face a problem or a job and afterwards? i.e. lost, insecure > confident, in control - use it in your communication strategy & design.

The aircraft engine failure occurs, passengers often get annoyed and frustrated. They also might lose to reach on time to some important occasions.

10. YOUR SOLUTION

SL

If you are working on an existing business, write down your current solution first fill in the canvas, and check how much it fits reality. If you are working on a new business proposition, then keep it blank until you fill in the canvas and come up with a solution that fits within customer limitations, solves a problem and matches the behaviour of the customer.

Preventable fuel problems such as exhaustion. Structural failures where a broken connecting rod, crank, valve, or camshaft is present account for seventeen percent of engine failures occurs.

8. CHANNELS OF BEHAVIOUR

CH

ONLINE
What kind of actions do customers take online? Extract online channels from #7

OFFLINE
What kind of actions do customers take offline? Extract offlinechannels from #7 and use them for customer development.

Online: Measure and manage all the sensor data

Offline: To checkthe physical hardware overlook and check for any open damages

4. REQUIREMENT ANALYSIS

4.1Functional Requirements:

Following are the functional requirements of the proposed solution.

Following are the functional requirements of the proposed solution. **FR No.**	**Functional Requirement (Epic)**	**Sub Requirement (Story / Sub-Task)**
FR-1	User Registration	Registration through Form.
FR-2	User Confirmation	Confirmation via email. Confirmation via OTP.
FR-3	User Infrastructure	A platform for machine learning. An appropriate GPU and CPU.
FR-4	User Network	Internet access is required for the web server to host the application and send users' test results through email.
FR-5	User Cost	The web server running costs.
FR-6	User Requirements	Understanding of how to enter data into an application.

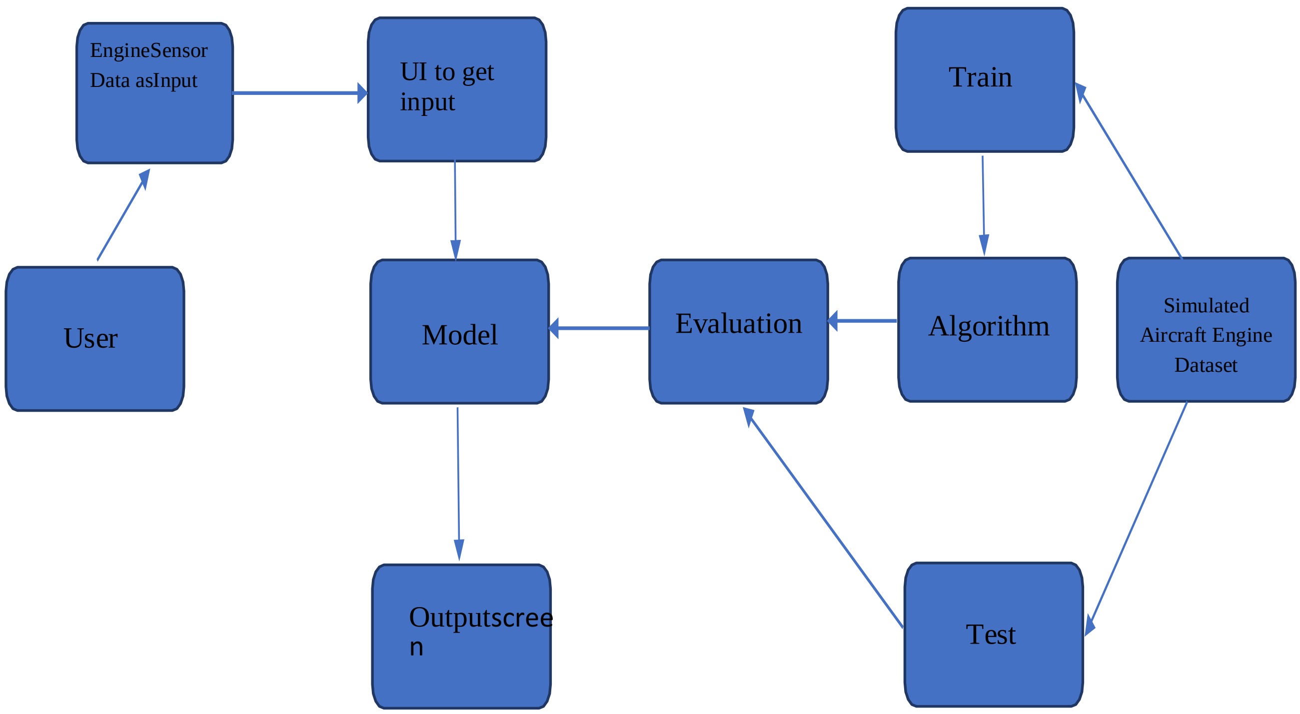
4.2 Non-Functional Requirements

Following are the non-functional requirements of the proposed solution.

FR No.	Non-Functional Requirement	Description
NFR-1	**Usability**	The application is too simple to use. It does not need special training.
NFR-2	**Security**	Both the user data and the web server hosting the application are secure.
NFR-3	**Reliability**	It specifies the probability of the performance of software with no failure for a particular number of uses or amount of time.
NFR-4	**Performance**	The machine learning model can predict outcomes very rapidly because it is quick.
NFR-5	**Availability**	All internet users must be able to access the web application, and it must be secure from denial-of-service attacks.
NFR-6	**Scalability**	The application needs to be flexible enough to scale up or down across various servers in response to demand.

5. PROJECT DESIGN

5.1 Data Flow Diagrams



5.2 Solution & Technical Architecture

Solution architecture is a complex process – with many sub-processes – that bridges the gap between business problems and technology solutions. Its goals are to:

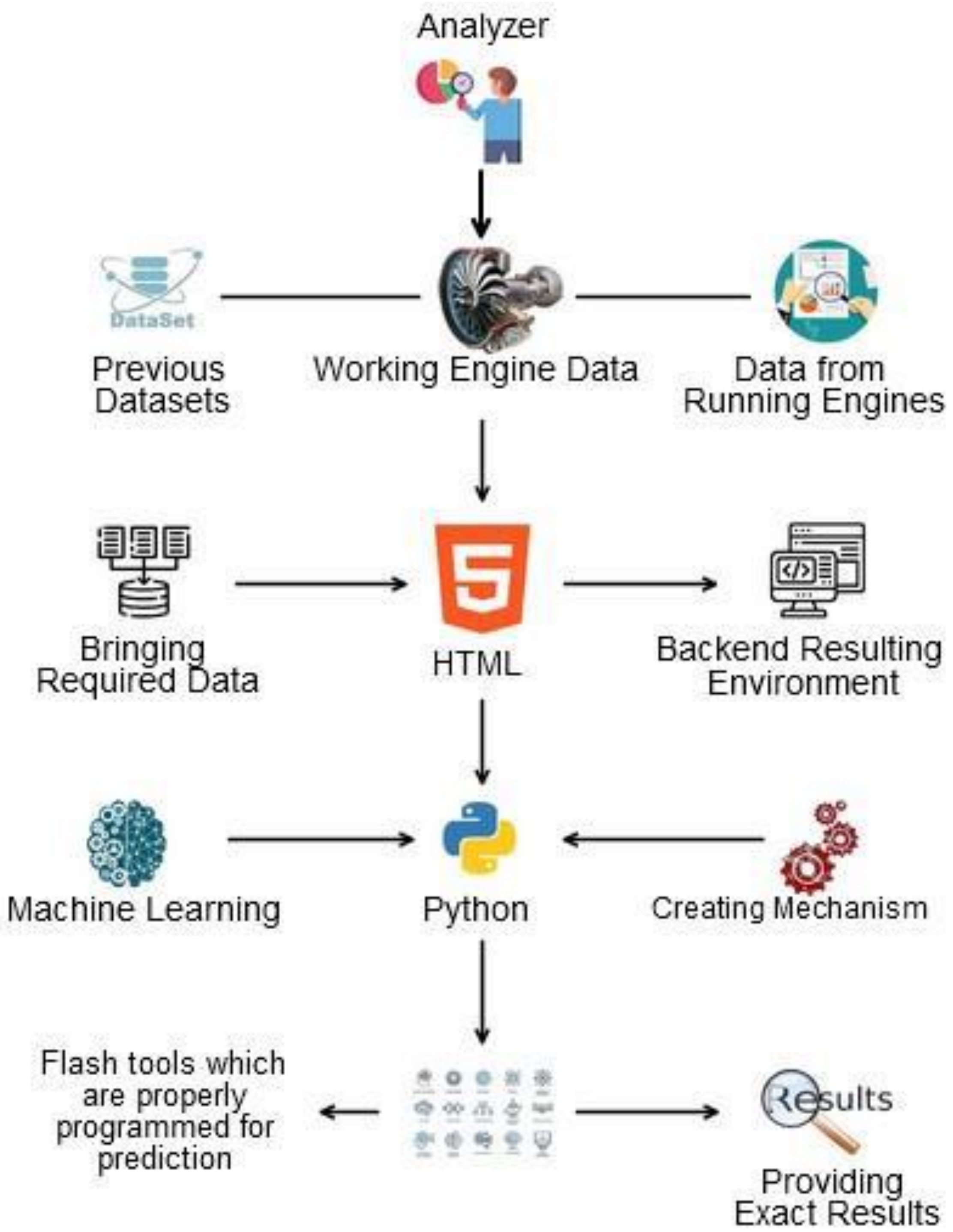
 Find the best tech solution to solve existing business problems.

 Describe the structure, characteristics, behaviour, and other aspects of the software to project stakeholders.

 Define features, development phases, and solution requirements.

 Provide specifications according to which the solution is defined, managed, and delivered.

Example - Solution Architecture Diagram:


Analyzer
DataSet
Previous Datasets
Working Engine Data
Data from Running Engines
Bringing Required Data
HTML
Backend Resulting Environment
Machine Learning
Python
Creating Mechanism
Flash tools which are properly programmed for prediction
Results
Providing Exact Results

5.3 User Stories

UserType	FunctionalRequirement (Epic)	User StoryNumber	UserStory/Task	Acceptancecriteria	Priority	Release
Customer orUser WebUser	Entering Aircraft EngineData	USN –1	Enter the required datarequestedintheformto predict the remainingcyclesofengine	Feedinput tothemodel forprediction	High	Sprint–1
		USN –2	EnterSubmittogettheoutput	Can get theremainingcyclesof engine	High	Sprint–1
		USN –3	View the Remaining cyclesofAircraftengine	Getthepredictedcycles	High	Sprint–1

6. PROJECT PLANNING & SCHEDULING

6.1 Sprint Planning & Estimation

Sprint	Functional Requirement (Epic)	User Story Number	User Story / Task	Story Points	Priority	Team Members
Sprint-1		USN-1	Download and pre-process the data set	1	High	Kanishkar, Karthikeyan
Sprint-2		USN-2	Train the model	2	High	Krishna Varshan,Kavya
Sprint-3		USN-3	Train, validate the dataset in the IBM Watson	3	Low	Karthikeyan
Sprint-4	Predict the engine’s remaining cycle from by entering inputs in created application	USN-4	Develop app using flask and deploy using IBM Watson.	5	Medium	Karthikeyan, Kanishkar, Krishna Varshan, Kavya

6.2 Sprint Delivery Schedule

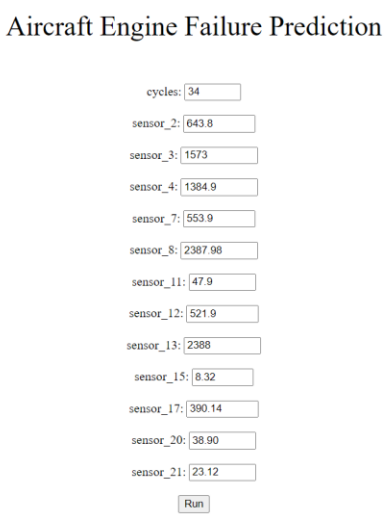
Sprint	Total Story Points	Duration	Sprint Start Date	Sprint End Date (Planned)	Story Points Completed (as on Planned End Date)	Sprint Release Date (Actual)
Sprint-1	20	6 Days	24 Oct 2022	29 Oct 2022	20	29 Oct 2022
Sprint-2	20	6 Days	31 Oct 2022	05 Nov 2022	20	05 Nov 2022
Sprint-3	20	6 Days	07 Nov 2022	12 Nov 2022	20	12 Nov 2022
Sprint-4	20	6 Days	14 Nov 2022	19 Nov 2022	20	19 Nov 2022

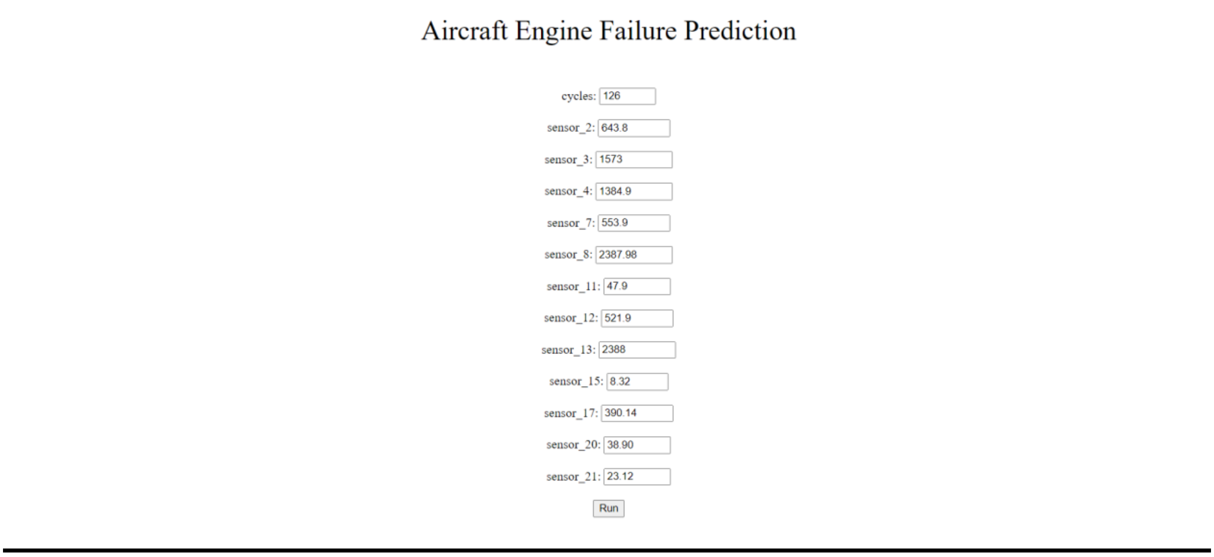
7. CODING & SOLUTIONING

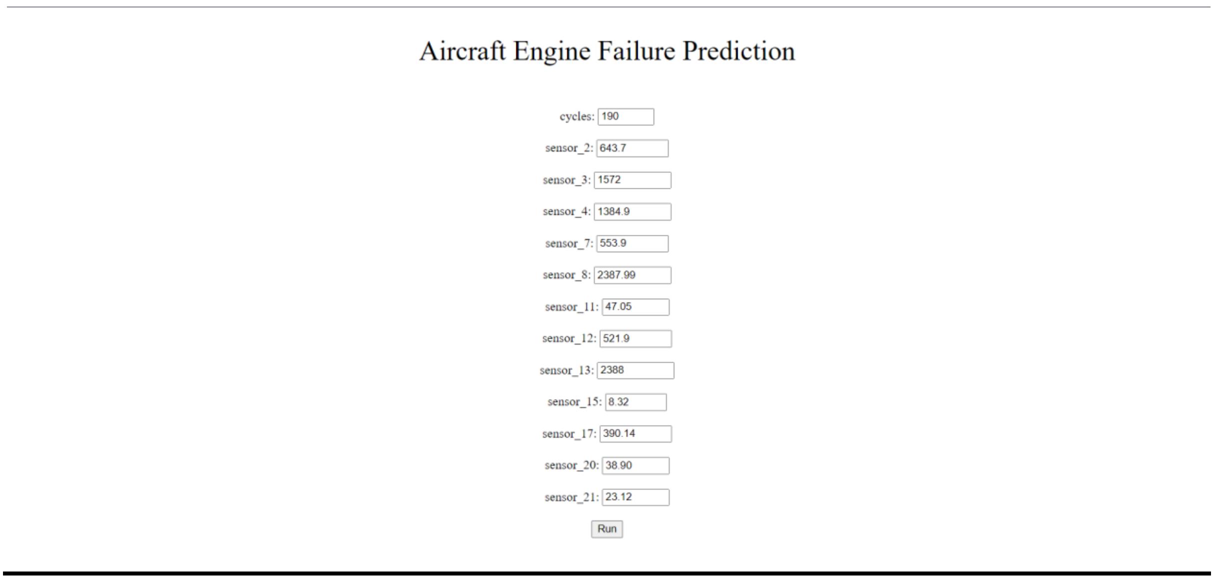
```
from flask import Flask, request, render_template
import pandas as pd
import joblib
import keras
import keras.backend as K
from keras.models import Sequential
from keras.layers import Dense , LSTM, Dropout
from keras.layers.core import Activation
from keras.callbacks import EarlyStopping, ModelCheckpoint
import random
import tensorflow as tf
import os
import numpy as np
from keras.models import load_model


# Declare a Flask app
app = Flask(__name__)


@app.route('/', methods=['GET', 'POST'])
def main():

    if request.method == "POST":

        model = load_model(r'C:\karthi\Projects\Nalai Thiran\Final 1\LSTM_model.h5')
```

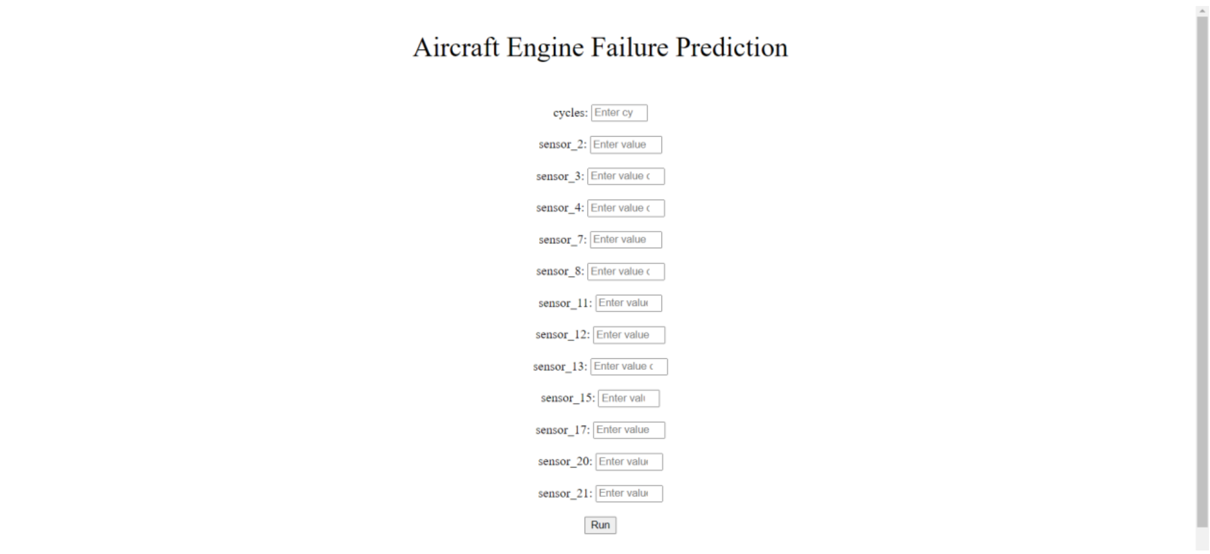
```
        sensor_2 = request.form.get("sensor_2")
        sensor_3 = request.form.get("sensor_3")
        sensor_4 = request.form.get("sensor_4")
        sensor_7 = request.form.get("sensor_7")
        sensor_8 = request.form.get("sensor_8")
        sensor_11 = request.form.get("sensor_11")
        sensor_12 = request.form.get("sensor_12")
        sensor_13 = request.form.get("sensor_13")
        sensor_15 = request.form.get("sensor_15")
        sensor_17 = request.form.get("sensor_17")
        sensor_20 = request.form.get("sensor_20")
        sensor_21 = request.form.get("sensor_21")

        # Put inputs to dataframe
        test_seq = pd.DataFrame([[sensor_2,sensor_3,sensor_4,sensor_7,sensor_8,sensor_11,sensor_12,sensor_13,sensor_15,sensor_17,sensor_20,sensor_21]])

        # Get prediction
        y_pred_test = model.predict(test_seq,verbose=1, batch_size=200)

    else:
        prediction = ""

    return render_template("website.html", output = prediction)


# Running the app
if __name__ == '__main__':
    app.run(debug = True)
```

8. TESTING

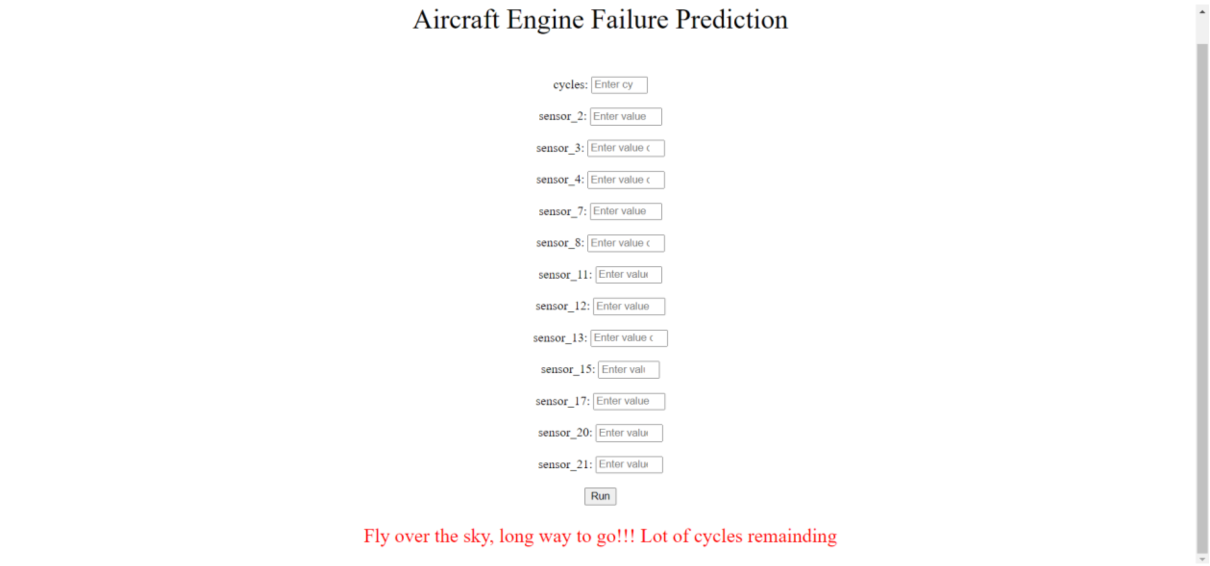



Aircraft Engine Failure Prediction
cycles: 126
sensor_2: 643.8
sensor_3: 1573
sensor_4: 1384.9
sensor_7: 553.9
sensor_8: 2387.98
sensor_11: 47.9
sensor_12: 521.9
sensor_13: 2388
sensor_15: 8.32
sensor_17: 390.14
sensor_20: 38.90
sensor_21: 23.12
Run

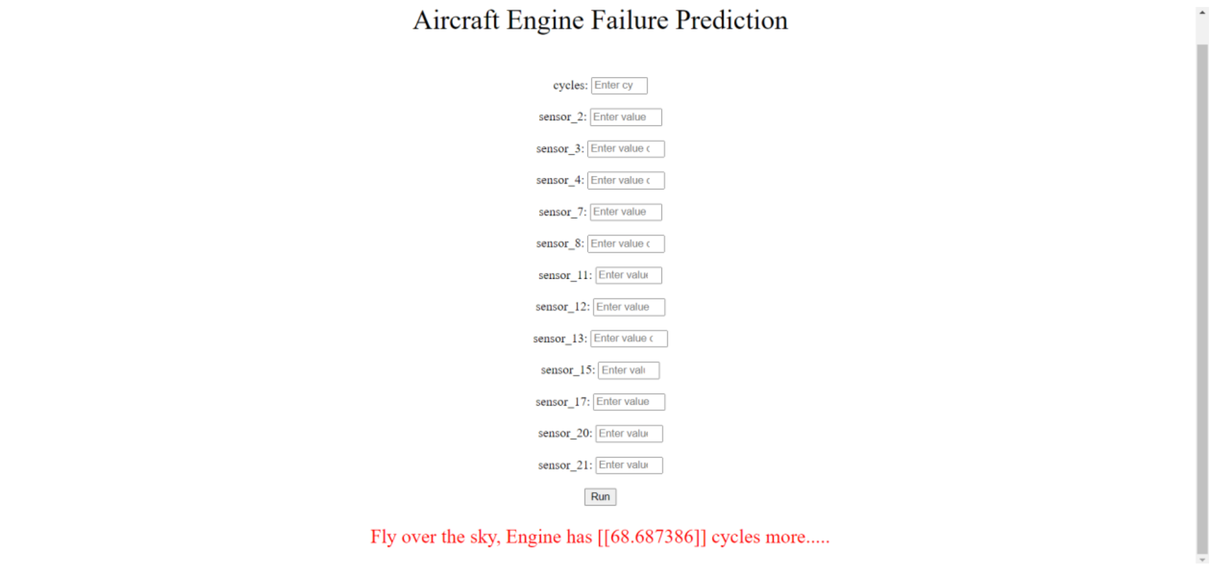

Aircraft Engine Failure Prediction
cycles: 190
sensor_2: 643.7
sensor_3: 1572
sensor_4: 1384.9
sensor_7: 553.9
sensor_8: 2387.99
sensor_11: 47.05
sensor_12: 521.9
sensor_13: 2388
sensor_15: 8.32
sensor_17: 390.14
sensor_20: 38.90
sensor_21: 23.12
Run


Aircraft Engine Failure Prediction
cycles: Enter cy
sensor_2: Enter value
sensor_3: Enter value c
sensor_4: Enter value c
sensor_7: Enter value
sensor_8: Enter value c
sensor_11: Enter valu
sensor_12: Enter value
sensor_13: Enter value c
sensor_15: Enter valu
sensor_17: Enter value
sensor_20: Enter valu
sensor_21: Enter valu
Run

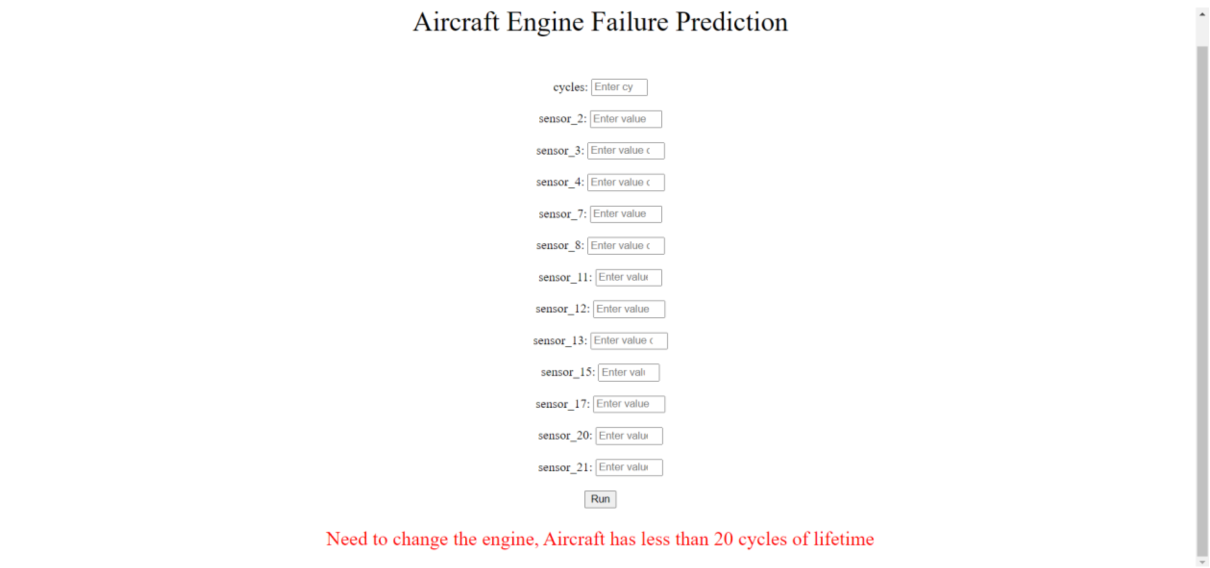
9. RESULTS



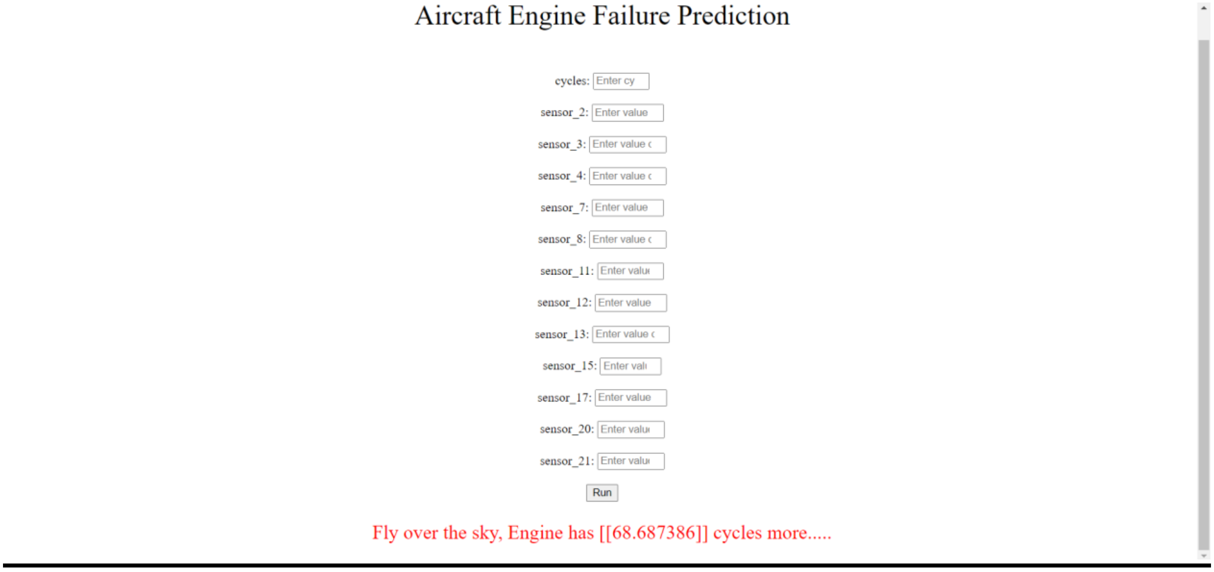
Aircraft Engine Failure Prediction
cycles:
sensor_2:
sensor_3:
sensor_4:
sensor_7:
sensor_8:
sensor_11:
sensor_12:
sensor_13:
sensor_15:
sensor_17:
sensor_20:
sensor_21:
Run
Fly over the sky, long way to go!!! Lot of cycles remainding



Aircraft Engine Failure Prediction
cycles:
sensor_2:
sensor_3:
sensor_4:
sensor_7:
sensor_8:
sensor_11:
sensor_12:
sensor_13:
sensor_15:
sensor_17:
sensor_20:
sensor_21:
Run
Fly over the sky, Engine has [[68.687386]] cycles more.....



Aircraft Engine Failure Prediction
cycles:
sensor_2:
sensor_3:
sensor_4:
sensor_7:
sensor_8:
sensor_11:
sensor_12:
sensor_13:
sensor_15:
sensor_17:
sensor_20:
sensor_21:
Run
Need to change the engine, Aircraft has less than 20 cycles of lifetime



10. ADVANTAGES & DISADVANTAGES

ADVANTAGES:

Machine learning and data science can predict future events, trends, and customer behaviour to a certain extent. These predictions can enable businesses to make better decisions about where to allocate resources and how to respond to changes in the market.

Machine learning algorithms use historical data as input to predict new output values. Recommendation engines are a common use case for machine learning. Other popular uses include fraud detection, spam filtering, malware threat detection, business process automation (BPA) and Predictive maintenance

With the ever-growing volume of data generated every day, it is increasingly difficult for humans to process and make sense of all this information. Machine learning can help businesses handle large amounts of data more efficiently and effectively and even use decision trees to take action on the information.

As humans after gaining experience improve themselves in the same way machine learning improve themselves and become more accurate and efficient in work. This led to better decisions. For example, in the weather forecast, the more data and experience the machine gets the more advanced forecast it will provide.

DISADVANTAGES:

Although machine learning is considered to be more accurate it is highly vulnerable. For example, a set of programs provided to the machine may be biased or consist of errors. The same program is used to make another forecast or prediction then there will be a chain of errors that could be formed which may, although recognized but take some time to find out the source of the error.

The more data a machine gets the more accurate and efficient it becomes thus more data is required to input to the machine for better forecasting or decision making. But it may sometimes not be possible. Also, the data must be unbiased and of good quality. Data requirements are problematic sometimes. As we have already seen that a little manipulation or biased data could lead to a long drawn error chain and therefore there are chances of the inaccuracy of interpretation also. Sometimes data without any error could also be interpreted inaccurately by the machine as the data provided previously may not fulfil all the basics of the machine.

11. CONCLUSION

Overall, the results show that by bringing together sufficient (big) high quality data, robust machine learning algorithms, and data science, machine learning-based predictive analytics can be an effective tool for engine design-space exploration during the conceptual design phase. It would help to identify the best engine design expeditiously amongst several candidates. The promising results of the predictive analytics show that machine-learning techniques merit further exploration for application in aircraft engine conceptual design.

To further improve the accuracy (and reduce the uncertainty) of TSFC prediction. the database needs to be expanded However, the limitation of publicly available engine data is a challenge to overcome.

12. FUTURE SCOPE

- Early predictions avoid the accident and other problems.

- The process maintenance become easier...
- Predicting future also saves the money and the resources,
- Controls the machine and its performance.
- Train model in various machines can useful for the performance and maintenance.
- Machine learning algorithms can used for the models and the models monitor the performances.
- The algorithms can be update in high performance like the solution it will find itself.

14.GITHUB AND DEMO LINK

Github Link:

https://github.com/IBM-EPBL/IBM-Project-5357-1658760171

Demo Link:
https://drive.google.com/file/d/1rU3TrQywHG1yYPV9Tk6r6XUanmwwlsr4/view?usp=share_link