Data Science Capstone

UAV Propeller Performance Analysis

Business Scenario

Problem statement:

The growing demand for small Unmanned Aerial Vehicles (UAVs) in civil and military applications necessitates addressing challenges in propulsion system optimization. Designing efficient propellers for small UAVs involves navigating trade-offs in size, power, and weight against range and endurance requirements. This project aims to understand and overcome aerodynamic complexities unique to small UAVs, enhancing their overall performance and adaptability.

Objective:

Develop a data-driven framework for enhancing the prediction of propeller performance, crucial for the evolving field of urban air mobility. Utilize modern research trends, incorporating both standalone and ensemble machine learning techniques to forecast thrust coefficient, power coefficient, and efficiency based on blade geometry and operational inputs.

Dataset Snapshot

Experiment_vol1.xlsx

Propeller's Name	Blade's Name	Propeller's Brand	Number of Blades	Propeller's Diameter	Propeller's Pitch	Advanced Ratio Input	RPM Rotation Input	Thrust Coefficient Output	Power Coefficient Output	Efficiency Output
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.165	4000	0.0993	0.0539	0.304
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.214	4000	0.0947	0.0543	0.374
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.255	4000	0.0916	0.0548	0.427
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.301	4000	0.0847	0.054	0.473
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.34	4000	0.0796	0.053	0.511
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.4	4000	0.0718	0.0504	0.57
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.438	4000	0.0659	0.0481	0.602
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.483	4000	0.0583	0.0451	0.625
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.531	4000	0.0497	0.041	0.644
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.567	4000	0.043	0.0372	0.655
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.615	4000	0.0336	0.0318	0.648
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.664	4000	0.0252	0.0265	0.632
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.705	4000	0.0172	0.0217	0.561
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.753	4000	0.0091	0.0162	0.424
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.79	4000	0.0025	0.0118	0.165
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.134	5004	0.1035	0.0523	0.264
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.169	5004	0.1016	0.0536	0.321
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.205	5004	0.0984	0.0538	0.375
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.239	5004	0.0953	0.054	0.422
ance 8.5x6.0 - 2	ance 8.5x6.0	ance	2	8.5	6	0.278	5004	0.0909	0.0542	0.466

Dataset Snapshot

Experiment_vol2.xlsx

Propeller's Name	Blade's Name	Propeller's Brand	Number of Blades	Propeller's Diameter	Propeller's Pitch	Advanced Ratio Input	RPM Rotation Input	Thrust Coefficient Output	Power Coefficient Output	Efficiency Output
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.113578	6043	0.128215	0.112438	0.129516
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.170594	6043	0.126315	0.112042	0.192328
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.227089	6043	0.122438	0.109617	0.253649
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.280419	6043	0.117189	0.106619	0.308221
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.337563	6043	0.112078	0.104211	0.363048
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.390673	6043	0.10651	0.101066	0.411711
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.453885	6043	0.099455	0.098394	0.45878
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.510619	6043	0.091677	0.093974	0.49813
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.563855	6043	0.084044	0.09007	0.526137
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.62544	6043	0.075631	0.085729	0.551764
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.681656	6043	0.066384	0.079786	0.567138
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.738534	6043	0.055651	0.071549	0.574443
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.793342	6043	0.045302	0.063238	0.568328
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.850782	6043	0.034358	0.054679	0.534592
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.912266	6043	0.022406	0.044442	0.459932
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.962425	6043	0.011545	0.035425	0.313629
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	1.026329	6043	-0.000567	0.025364	-0.02293
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	1.075117	6043	-0.010926	0.015609	-0.752619
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	1.140687	6043	-0.023374	0.00614	-4.343338
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.084966	8043	0.131715	0.113065	0.098981
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.127626	8043	0.128989	0.111854	0.147177
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.170211	8043	0.127574	0.111773	0.194274
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.212723	8043	0.125484	0.110844	0.24082
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.25561	8043	0.122255	0.108631	0.287666
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.295666	8043	0.118147	0.105975	0.329624
apcff 4.2x4.0 - 2	apcff 4.2x4.0	apcff	2	4.2	4	0.338717	8043	0.114313	0.104116	0.371895

Dataset Snapshot

Experiment_vol3.xlsx

Propeller's Name	Blade's Name	Propeller's Brand	Number of Blades	Propeller's Diameter	Propeller's Pitch	Advanced Ratio Input	RPM Rotation Input	Thrust Coefficient Output	Power Coefficient Output	Efficiency Output
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.18826	3035	0.122679	0.128448	0.179806
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.235034	3035	0.12122	0.125246	0.227478
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.281323	3035	0.120995	0.121858	0.27933
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.32557	3035	0.119506	0.117865	0.330103
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.373029	3035	0.118787	0.114089	0.38839
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.420446	3035	0.115536	0.111905	0.434088
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.470714	3035	0.112198	0.11341	0.465677
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.516983	3035	0.103056	0.11222	0.474761
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.564317	3035	0.099743	0.111501	0.504807
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.610388	3035	0.095504	0.108877	0.535416
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.658923	3035	0.092848	0.106396	0.575017
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.705153	3035	0.087716	0.102623	0.60272
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.753709	3035	0.085402	0.100937	0.63771
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.79957	3035	0.082366	0.099108	0.664495
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.851035	3035	0.077564	0.097297	0.678434
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.895695	3035	0.072036	0.094635	0.681795
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.938607	3035	0.066202	0.091159	0.681639
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.800703	3042	0.081963	0.098897	0.663606
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.850461	3042	0.078241	0.097681	0.681205
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.890913	3042	0.072393	0.094584	0.681891
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.947417	3042	0.065569	0.091038	0.68237
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	0.992531	3042	0.060366	0.088344	0.678204
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	1.040272	3042	0.053792	0.084719	0.660523
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	1.092291	3042	0.045644	0.079319	0.628556
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	1.131503	3042	0.038871	0.074417	0.591029
ancf 10.0x12.0 - 2	ancf 10.0x12.0	ancf	2	10	12	1.177277	3042	0.030302	0.067654	0.527314

Dataset Description

Experiment_vol.xlsx

Variables	Description
Propeller's Name	Name of the propeller
Blade's Name	Name of the blade
Propeller's Brand	Brand of the propeller
Number of Blades	Number of blades in that propeller
Propeller's Diameter	Diameter of the propeller
Propeller's Pitch	Distance the propeller would move forward in one rotation
Advanced Ratio Input	Ratio of the freestream fluid speed to the propeller
RPM Rotation Input	Rotation per minute
Thrust Coefficient Output	Signifies the degree to which the thrust is amplified by the nozzle
Power Coefficient Output	CP = Power Absorbed / (density * n^3 * d^5)
Efficiency Output	The propeller efficiency (kgf/W) can be calculated by dividing the thrust by the mechanical power.

Note: Description for Experiment_vol1.xlsx, Experiment_vol2.xlsx, and Experiment_vol3.xlsx

Dataset Snapshot

Geom_vol1.xlsx

Blade's Name	Propeller's Brand	Propeller's Diameter	Propeller's Pitch	Adimensional Chord - c/R	Adimensional Radius - r/R	beta - Angle Relative to Rotation
apc29ff 9.0x5.0	apc29ff	9	5	0.16	0.15	31.68
apc29ff 9.0x5.0	apc29ff	9	5	0.146	0.2	34.45
apc29ff 9.0x5.0	apc29ff	9	5	0.144	0.25	35.93
apc29ff 9.0x5.0	apc29ff	9	5	0.143	0.3	33.33
apc29ff 9.0x5.0	apc29ff	9	5	0.143	0.35	29.42
apc29ff 9.0x5.0	apc29ff	9	5	0.146	0.4	26.25
apc29ff 9.0x5.0	apc29ff	9	5	0.151	0.45	23.67
apc29ff 9.0x5.0	apc29ff	9	5	0.155	0.5	21.65
apc29ff 9.0x5.0	apc29ff	9	5	0.158	0.55	20.02
apc29ff 9.0x5.0	apc29ff	9	5	0.16	0.6	18.49
apc29ff 9.0x5.0	apc29ff	9	5	0.159	0.65	17.06
apc29ff 9.0x5.0	apc29ff	9	5	0.155	0.7	15.95
apc29ff 9.0x5.0	apc29ff	9	5	0.146	0.75	14.87
apc29ff 9.0x5.0	apc29ff	9	5	0.133	0.8	13.82
apc29ff 9.0x5.0	apc29ff	9	5	0.114	0.85	12.77
apc29ff 9.0x5.0	apc29ff	9	5	0.089	0.9	11.47
apc29ff 9.0x5.0	apc29ff	9	5	0.056	0.95	10.15
apc29ff 9.0x5.0	apc29ff	9	5	0.022	1	8.82
apce 10.0x5.0	apce	10	5	0.13	0.15	32.76

Dataset Snapshot

Geom_vol2.xlsx

Blade's Na	Propeller's Brand	Propeller's Diameter	Propeller's Pitch	Adimensional Chord - c/R	Adimensional Radius - r/R	beta - Angle Relative to Rotation
apcff 4.2x	apcff	4.2	4	0.2027	0.15	38.363
apcff 4.2x	apcff	4.2	4	0.1909	0.2	42.864
apcff 4.2x	apcff	4.2	4	0.1865	0.25	45.208
apcff 4.2x	apcff	4.2	4	0.1823	0.3	44.502
apcff 4.2x	apcff	4.2	4	0.18	0.35	42.724
apcff 4.2x	apcff	4.2	4	0.1817	0.4	40.263
apcff 4.2x	apcff	4.2	4	0.186	0.45	37.416
apcff 4.2x	apcff	4.2	4	0.1895	0.5	34.613
apcff 4.2x	apcff	4.2	4	0.1902	0.55	32.197
apcff 4.2x	apcff	4.2	4	0.188	0.6	30.083
apcff 4.2x	apcff	4.2	4	0.183	0.65	28.195
apcff 4.2x	apcff	4.2	4	0.175	0.7	26.509
apcff 4.2x	apcff	4.2	4	0.1642	0.75	24.943
apcff 4.2x	apcff	4.2	4	0.1506	0.8	23.468
apcff 4.2x	apcff	4.2	4	0.1341	0.85	21.855
apcff 4.2x	apcff	4.2	4	0.1145	0.9	19.775
apcff 4.2x	apcff	4.2	4	0.0855	0.95	17.162
apcff 4.2x	apcff	4.2	4	0.009	1	15.732
apcff 9.0x	apcff	9	4	0.1693	0.15	33.068
apcff 9.0x	apcff	9	4	0.1671	0.2	35.152
apcff 9.0x	apcff	9	4	0.1665	0.25	34.443
apcff 9.0x	apcff	9	4	0.1653	0.3	30.962
apcff 9.0x	apcff	9	4	0.1659	0.35	27.381

Dataset Snapshot

Geom_vol3.xlsx

Blade's Name	Propeller's Brand	Propeller's Diameter	Propeller's Pitch	Adimensional Chord - c/R	Adimensional Radius - r/R	beta - Angle Relative to Rotation
nr640 5x3.16	nr640	5	3.156702054	0.1061	0.3	32.091
nr640 5x3.16	nr640	5	3.156702054	0.1228	0.35	29.631
nr640 5x3.16	nr640	5	3.156702054	0.1382	0.4	27.052
nr640 5x3.16	nr640	5	3.156702054	0.1489	0.45	24.286
nr640 5x3.16	nr640	5	3.156702054	0.1529	0.5	22.047
nr640 5x3.16	nr640	5	3.156702054	0.1513	0.55	20.101
nr640 5x3.16	nr640	5	3.156702054	0.1469	0.6	18.497
nr640 5x3.16	nr640	5	3.156702054	0.1404	0.65	17.14
nr640 5x3.16	nr640	5	3.156702054	0.1328	0.7	16.012
nr640 5x3.16	nr640	5	3.156702054	0.123	0.75	15
nr640 5x3.16	nr640	5	3.156702054	0.1131	0.8	14.193
nr640 5x3.16	nr640	5	3.156702054	0.1019	0.85	13.435
nr640 5x3.16	nr640	5	3.156702054	0.089	0.9	12.796
nr640 5x3.16	nr640	5	3.156702054	0.0753	0.95	12.222
nr640 5x3.16	nr640	5	3.156702054	0.0605	1	11.662
nr640 5x4.29	nr640	5	4.287923303	0.1061	0.3	32.091
nr640 5x4.29	nr640	5	4.287923303	0.1228	0.35	29.631
nr640 5x4.29	nr640	5	4.287923303	0.1382	0.4	27.052
nr640 5x4.29	nr640	5	4.287923303	0.1489	0.45	24.286
nr640 5x4.29	nr640	5	4.287923303	0.1529	0.5	22.047
nr640 5x4.29	nr640	5	4.287923303	0.1513	0.55	20.101
nr640 5x4.29	nr640	5	4.287923303	0.1469	0.6	18.497
nr640 5x4.29	nr640	5	4.287923303	0.1404	0.65	17.14

Dataset Description

Geom_vol.xlsx

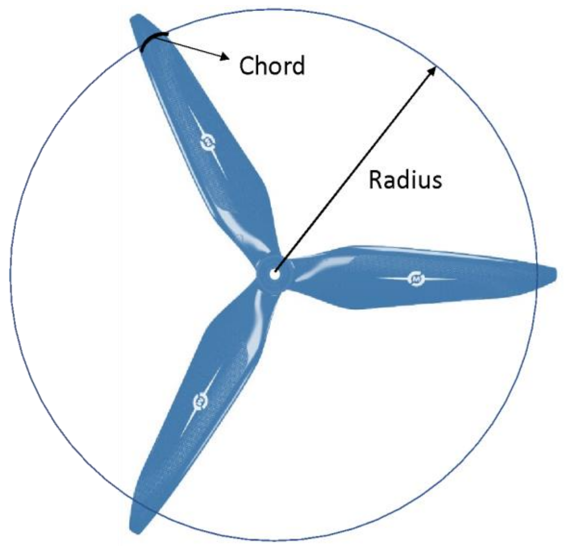
Variables	Description
Blade's Name	Name of the blade
Propeller's Brand	Brand of propeller
Propeller's Diameter	Diameter of propeller
Propeller's Pitch	Distance the propeller would move forward in one rotation
Adimentional Chord – c/R	Distribution of chord-to-radius (C/R) values and the curve type
Beta- Angle relative to rotation	Angle of the propeller blades relative to the plane of rotation

Note: Description for Geom_vol1.xlsx, Geom_vol2.xlsx, and Geom_vol3.xlsx

Project Task: Week 2

Data science

1. Read all the files in the Python environment and append all the three versions for experiment data and blade geometry data. Now, you have two datasets that contain all the information.
2. Change the variable names in line with Python identifier naming convention.
3. Adimensional Radius and Adimensional Chord values are provided. Multiplying these values with Radius(R) of the blade will give you radius and chord distributions. Find these distributions for all the blades of all the propellers. Picture provided below shows a propeller with three blades.



Project Task: Week 2

Data science

4. For each propeller, find out the area of each blade and total area of all the blades. For this calculation, chord and radius values are used. Mathematically, definite integration techniques help to perform this calculation. Explore numpy.trapz for this calculation. This function helps to perform integration along the given axis using the composite trapezoidal rule.
5. Calculate the disc areas of all the propellers. Area of a disc is A=πr^2 (where r is the radius of the disc which is half of the diameter)
6. Solidity values of propellers are considered to be very important factor affecting the performance of a UAV. Calculate the propeller's solidity. It is a dimensionless quantity which is a ratio of the area of the blades to the area of the disc.

Project Task: Week 2

Data science

7. Collate solidity values calculated above for all the propellers with the experiment data
8. Check if you were able to calculate the solidity values of all the propellers. Describe your findings in detail. Use appropriate visualization to showcase your findings.
9. Create appropriate visualizations to perform bivariable analysis. Share your thoughts.
10. Create a heatmap to showcase correlation between the variables

Project Task: Week 2

Machine learning

11. Do you have missing values in the data? Perform missing value treatment.
12. Create models to predict performance of a propeller. Performance metrics have been described earlier. Please follow the instructions given below:
    - Build your model for those propellers which have 2 blades. Then, evaluate the model for other propellers
    - Use Gradient BOOST technique for model building
    - Create 3 types of models – Without missing value imputation, with missing value imputation and without Solidity. Compare the performance of all the models. Use appropriate visualizations to support your arguments.

Project Task: Week 1

SQL

1. In experiment 1 database, find the total number of propellers which have thrust coefficient output more than 12%
2. In experiment 1 database, reorder the database in descending order based on efficiency output
3. Find the least 100 performing propellers based on power coefficient output in experiment 1 database.
4. Merge the experiment 1, 2, and 3 databases, and find the total number of propellers which have negative or zero efficiency output

Project Task: Week 2

Tableau

1. Create a dashboard in tableau by choosing appropriate chart types and metrics useful for the business.
2. The emphasis must be given to data-storytelling.

Thank You