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Machine Learning for Advanced Aircraft Load Prediction & Optimization

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Content

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❑**Problem Definition:** Enhance aircraft load prediction reliability.

❑**Data Collection:** Collect historical flight and sensor data.

❑**Data Cleaning:** Analyze and clean data for patterns and anomalies.

❑**Data Preparation:** Engineer features and split data into training/testing sets.

❑**Model Selection:** Choose suitable ML algorithms.

❑**Model Training:** Train models and tune hyperparameters.

❑**Model Evaluation:** Assess performance with metrics.

❑**Model Deployment and Monitoring:** Deploy the best model in production and monitoring and continuously monitor and retrain the model.

❑**Conclusion**

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Problem Definition - Executive Summary

Challenges with Traditional Methods: Traditional aircraft load calculation methods struggle with complex non-linear relationships.

ML Integration: Integration of machine learning (ML) enhances load prediction accuracy and optimization.

Data and Feature Engineering: Detailed data collection, feature engineering, model training, and selection processes.

Model Performance: The Gradient Boosting model significantly improved prediction accuracy.

Comprehensive Calculations: Detailed load calculations, geometric specifications, and technical considerations for the Faez aircraft.

Methodology Integration: Combined traditional aerospace engineering methodologies with modern ML approaches.

Broad Condition Coverage: Covered various flight conditions, including temperature levels, weather, and operational scenarios.

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Problem Definition - Introduction

Advanced prediction models and simulations were used to meet JAR-23 safety and performance standards.

Comprehensive Analysis Across All Aircraft Parts:

Employed thorough evaluation techniques to ensure optimal load distribution and structural integrity.

Successful Creation and Flight:

The Light aircraft completed its maiden flight, validating the efficacy of our predictive models and testing protocols.

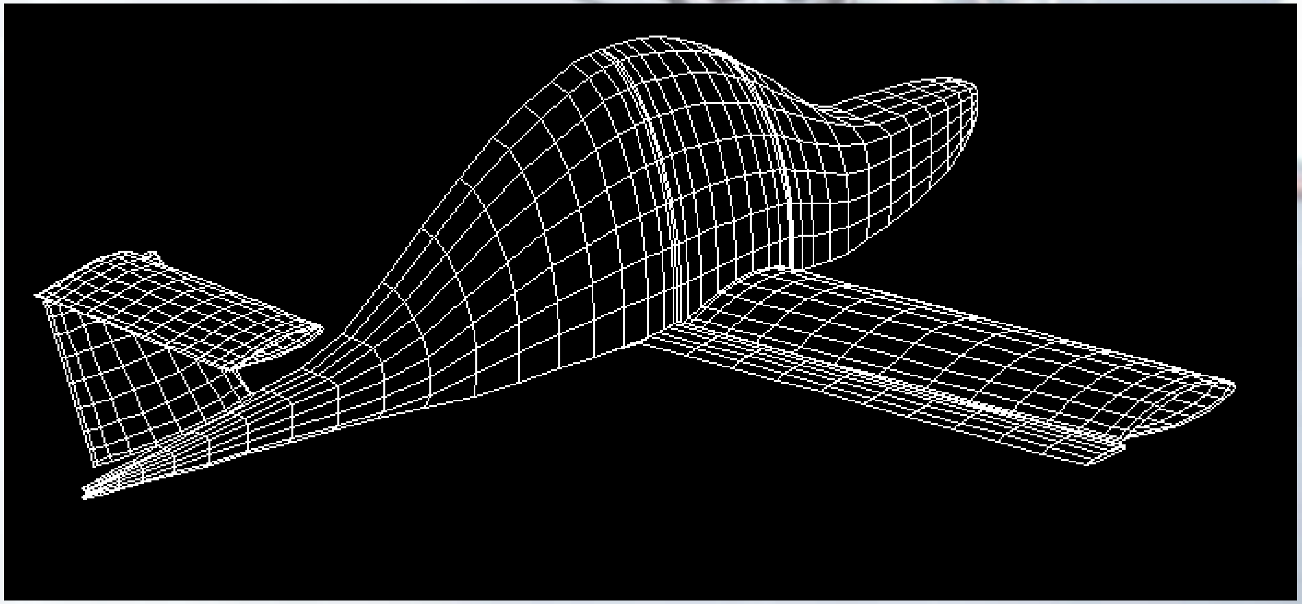
Cost-Effective Testing Strategy:

Leveraged prediction models and simulations to significantly reduce reliance on expensive wind tunnel tests.

Confirmed design viability and safety through simulations before physical prototyping, leading to substantial cost savings

Data Collection and Cleaning

- Initial load estimation based on JAR-23 aviation standards.
- Final load calculations using CMARC software, ensuring compliance with industry standards.
- Historical flight data, sensor measurements, and environmental data.
- Feature engineering to improve model training.



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Data Preparation - Initial Load Estimation of Light Aircraft

General Information:

Maximum Takeoff Weight: 170 kg

Maximum Load Factor: 6

Tail Assembly Specifications:

Horizontal Tail Area: 0.61 m²

Vertical Tail Area: 0.38 m²

Horizontal Tail Span: 1.55 m

Vertical Tail Span: 0.67 m

Horizontal Tail Root Chord: 0.40 m

Vertical Tail Root Chord: 0.65 m

Vertical Tail Tip Chord: 0.46 m

Wing Specifications:

Wing Area: 3.1 m²•

Wing Span: 5 m•

Wing Chord: 0.625 m•

Aspect Ratio: 7.8•

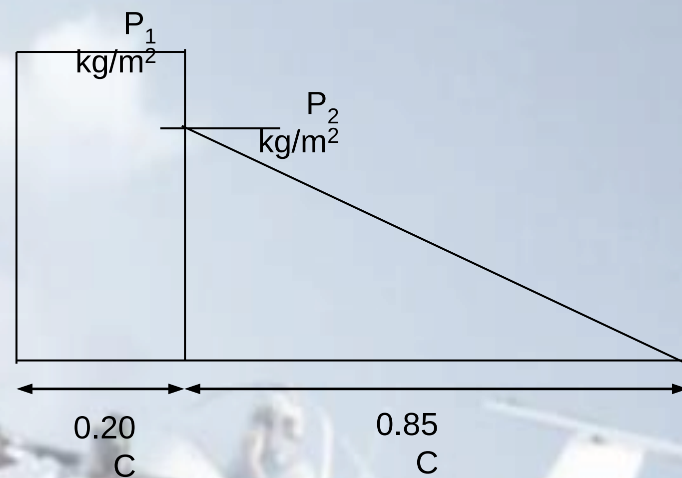
Data Preparation - Basis for Loading the Light Aircraft

Pressure distribution along the wing chord is determined by:

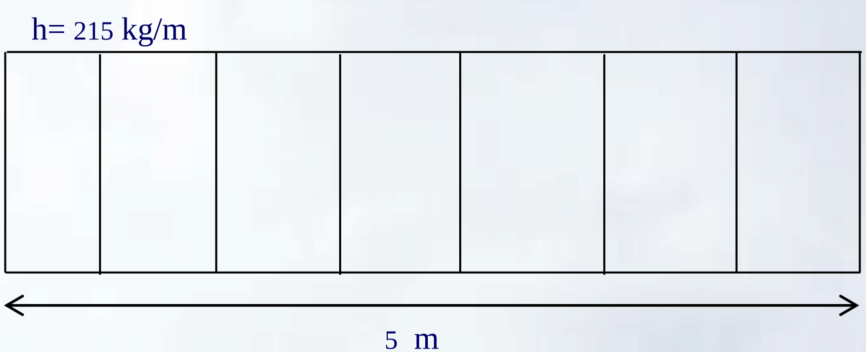
P_1=2.5 h(y) / C
P_2=h(y) / 0.8 C

So:

P_1=860 (kg/m^2)
P_2=430 (kg/m^2)



Load Distribution Along the Wing Chord



Distributed Load Along the Wing Span

Distributed Load Along the Wing Span

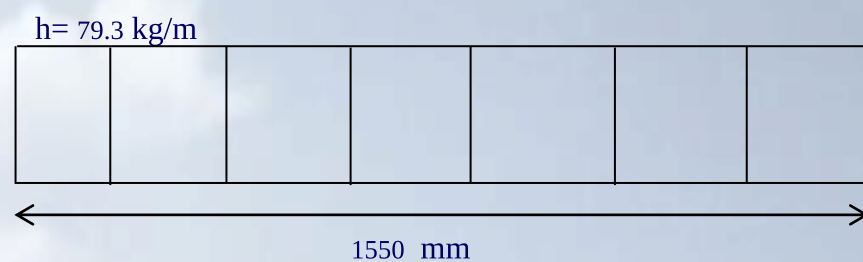
F=n.W
h(y)=1.05(F/S)C
C_r=C_t=0.625 (m)
S=3.12 (m^2)

Data Preparation - Basis for Loading the Light Aircraft

Horizontal Tail Loading
Content:
Based on JAR-23 Appendix B, the distributed load along the horizontal tail span is:

nw/s=329 (kg/m²)

$F_{H.T}$=121 (kg)



Distributed Load Along the Horizontal Tail

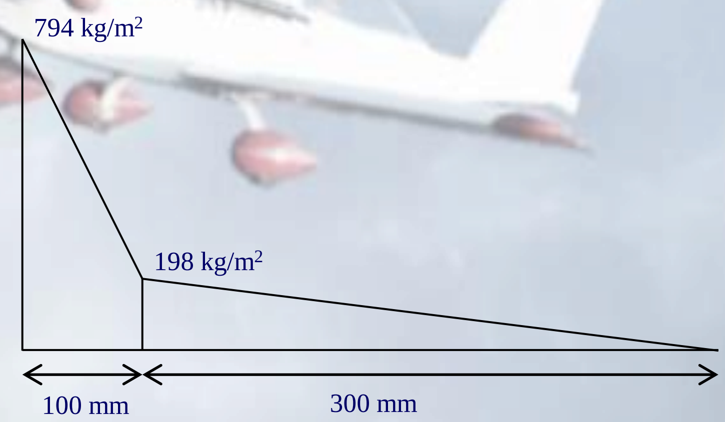
Load Distribution Along the Horizontal Tail Chord

Content:

The load distribution spans from 100 mm with loads ranging from 794 kg/m² to 198 kg/m².

Upward deflection load: 89.4 kg

Downward deflection load: 62 kg
$F_{H.T}$=62 (kg)
$F_{H.T}$=89.4 (kg)

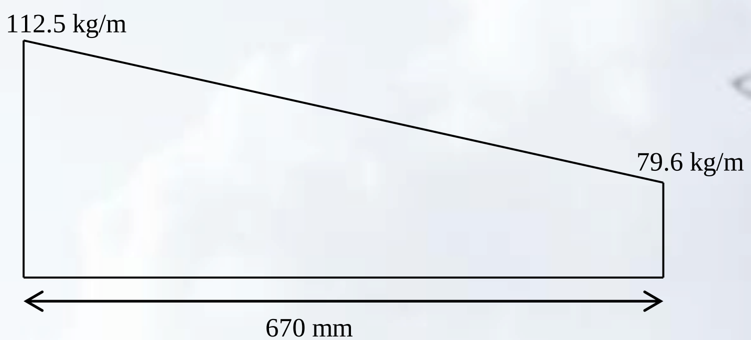


Load Distribution Along the Horizontal Tail Chord

Data Preparation - Basis for Loading the Light Aircraft

Vertical Tail Loading Content:

The total vertical tail load is 65.8 kg, with distributed loads calculated as follows:



Load Distribution Along the Vertical Tail Chord

$F_{V.T}$=65.8 (kg)

Spanning 670 mm, the load per unit area ranges from 112.5 kg/m to 79.6 kg/m.

Data Preparation - Basis for Loading the Light Aircraft

Geometric Specifications of Light Aircraft:

Force(kg)		
Wing	H.T	V.T
1070	121	66

Final Loading Calculations

	Wing (semi.span)	H.T (semi.span)	V.T (semi.span)
Forc(kg)	535	61	66
Location(m)	1.25	0.3875	0.158
Shear Force(kg)	535	61	66
Ben.Moment(kg.m)	669	23.6	10.4

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Data Preparation - Basis for Loading the Light Aircraft

Geometric Specifications of Light Aircraft:

Wing	
Wing span(m)	5
Wing area(m^2)	3.1
Aspect ratio	7.8
Wing chord (m)	0.625
Taper ratio	1
Fusalage	
length	3.9
Max width	0.9
Max length	0.85
Vertical tail	
span	1
Tip chord	0.35
Root chord	0.25
Area	2*0.616
Aspect ratio	1.62
Airfoil	NACA 0012
Horizontal tail	
span	2.4
chord	0.5
area	1.08
Aspect ratio	5.23
airfoil	NACA0010

<u>Geometric Specifications of Light Aircraft:</u>

- **Total Aircraft Weight: 170 kg**
- **Positive Flight Load Factor: 6**
- **Negative Flight Load Factor: -3**
- **Maximum Mach Number: 0.26**
- **Moment of Inertia (X-axis): 63.13 kg.m²**
- **Moment of Inertia (Y-axis): 92.26 kg.m²**
- **Distance from Horizontal Tail Force Application to CG: 2394 mm**
- **Moment of Inertia (Z-axis): 137.8 kg.m²**

Data Preparation - Basis for Loading the Light Aircraft

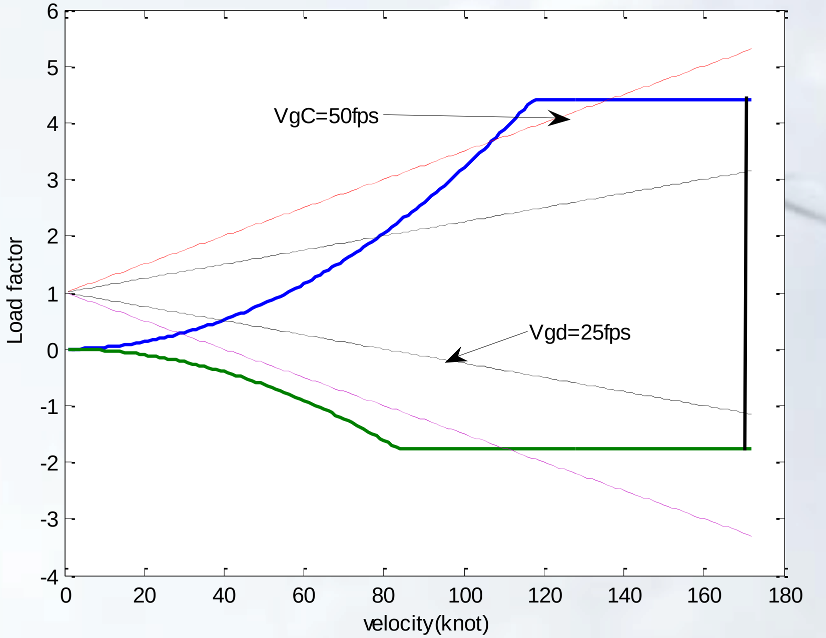
Aerodynamic Coefficients and Stability Derivatives:

Coefficient	***Value***
Cl0	*0.325*
Cla	*0.112*
Clde	*0.00405*
Clq	*0.111*
Cm0	*0.05*
Cma	*-0.0175*
Cmde	*-0.0145*
Cmq	*-0.242*
Cm0 with out elevator	*-0.0052*
Cma with out elevator	*-0.004*
Cmq with out elevator	*-0.01378*

Data Preparation - Basis for Loading the Light Aircraft

The V-n diagram examines the aircraft's wing loading in all specified conditions. The critical wing conditions are examined after the aircraft balance calculations, and the results are analyzed. The V-n diagram below shows the load factor vs. speed relationship, indicating balance points throughout the flight envelope.

V-n Diagram



Data Preparation - Light Aircraft Flight Conditions

Table of Flight Conditions at Zero Altitude

Case No.	n	M	Cy	V (km/h)	Q (kg/m2)	condition
1	6	0.18	1.41	220	233.4	Design maneuver VA
2	6	0.213	1	261	328.5	Design dive maneuver Vd
3	4.8	0.171	1.2	209	210.7	Design cruise maneuver Vc
4	3.4	0.213	0.568	261	328.5	Positive gust at dive speed
5	-1.4	0.213	-0.234	261	328.5	Negative gust at dive speed
6	-3	0.213	-0.5	261	328.5	Negative maneuver at dive speed
7	-3	0.147	-1.053	180	156.25	Negative stall maneuver
8	-2.8	0.171	-0.73	209	210.7	Negative cruise design maneuver V
9	1	0.074	1.41	90	39	Stalling at 1g
10	1	0.213	0.167	261	328.5	Equilibrium at dive speed Vd
11	1	0.171	0.26	209	210.7	Equilibrium at speed VA

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Data Preparation - Light Aircraft Flight Conditions

Table of Flight Conditions with 12 Degree Flap

Case No.	n	M	C_y	V (km/hr)	Q (kg/m^2)	condition
12	2	0.1	1.66	117	66	Positive Stall Maneuver
13	2	0.12	1.03	148.5	106.4	Positive Maneuver at Dive Speed

Table of Flight Conditions with 27 Degree Flap

Case No.	n	M	C_y	V (km/h)	Q (kg/m^2)	condition
14	2	0.084	2.17	102.4	50.6	Positive Stall Maneuver
15	2	0.092	1.81	112	60.5	Positive Gust
16	2	0.11	1.35	130	81.5	Positive Maneuver at Dive Speed

Required Parameters for Balancing Light Aircraft

X_{cg}	C_{L0}	(Cla)deg/1	(Clde)deg/1	(Clq)deg/1
0.24	0.26	0.0881	0.2945	0.1282
0.325	0.26	0.0881	0.2945	0.1138
0.4	0.26	0.0881	0.2945	0.0995

X_{cg}	C_{m0}	$C)_{ma}$deg/1(	$C)_{mde}$deg/1(	$C)_{mq}$rad/1(
24%	-0.00221	-0.03182	-0.1129	-0.34104
32.50%	0.01858	-0.02477	-0.11056	-0.3253
40%	0.03935	-0.01772	-0.10823	-0.3115

Aerodynamic Coefficients and Specifications of Light Aircraft

X_{cg}	C_{m0}	C_{ma} (1/deg)	C_{mq} (1/rad)
0.24	-0.0162	0.007	-0.0106
0.325	0.0053	0.0147	-0.008
0.4	0.0267	0.02239	-0.0085

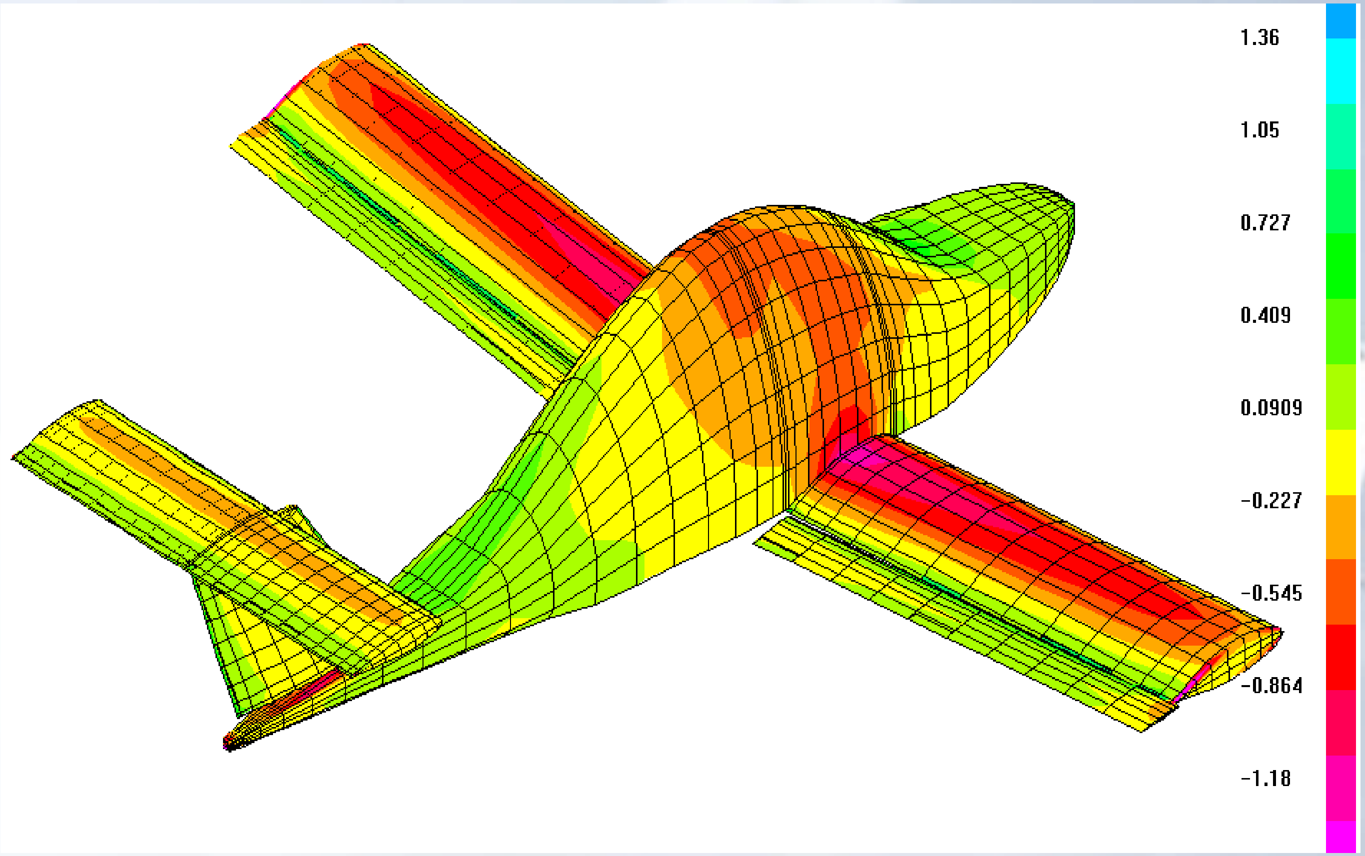
Data Preparation - Loading Conditions for Light Aircraft

The loading of the Light aircraft is carried out using CMARC software. The initial load estimates are based on JAR-23 aviation standards.

Case No.	n	M	ALFA (deg)	Dele. (deg)	Fwing(kg)	Ftail (kg)
1	6	0.18	14.1	-5.4	1005.3	14.7
2	6	0.213	9.1	-3.58	1008	11.7
3	4.8	0.171	12.1	-4.62	805	11
4	3.4	0.213	3.74	-1.56	575.8	2.2
5	-1.4	0.213	-6.15	1.8	-222	-16
6	-3	0.213	-9.4	3	-488.4	-21.6
7	-3	0.147	-16.2	5.4	-494	-16
8	-2.8	0.171	-12.2	4	-459	-17
9	1	0.074	-0.32	0.072	173.5	-3.5
10	1	0.213	-1.17	0.31	176.5	-6.5
11	1	0.171	-1.45	-0.015	172.8	-2.8

Data Preparation - Loading of Light Aircraft

Pressure Distribution Schematic of Light Aircraft in Postmarc Environment



Data Preparation - Loading of Light Aircraft

Balance and Critical Conditions of Light Aircraft

case No.	n	v (m/s)	much	alpha (deg)	deltaelevator (deg)	Fht (kg)
1	6.0	61	0.180	14.146	-4.386	39.886
2	6.0	73	0.213	9.109	-2.856	36.585
3	4.8	58	0.171	12.177	-3.726	31.127
4	3.4	73	0.213	3.762	-1.147	15.894
5	-1.4	73	0.213	-6.154	1.627	-22.786
6	-3.0	73	0.213	-9.444	2.679	-35.519
7	-3.0	50	0.147	-16.271	4.642	-29.539
8	-3.0	58	0.171	-12.267	3.470	-29.836
9	1.0	61	0.180	-0.326	0.241	0.097
10	1.0	73	0.213	-1.173	0.431	-3.205
11	1.0	58	0.171	-0.010	0.170	0.887

case No.	Fwing (kg)	v (km/hr)	Cl	Q(kg/m^2)	dfhm	fhb	dfhm+fhb	Aman	De.man
1	980.11	220.000	1.401	12.507	64.49	40.27	104.763	14.284	-4.799
2	983.42	261.000	0.995	5.186	64.49	36.97	101.462	9.207	-3.150
3	784.87	209.000	1.242	9.267	64.49	31.51	96.004	12.330	-4.184
4	562.11	261.000	0.564	0.885	64.49	16.28	80.771	3.861	-1.441
5	-215.21	261.000	-0.232	2.367	-64.49	-23.17	-87.663	-6.252	1.920
6	-474.48	261.000	-0.498	5.574	-64.49	-35.91	-100.395	-9.542	2.972
7	-480.46	180.000	-1.046	16.546	-64.49	-29.93	-94.416	-16.477	5.260
8	-446.16	209.000	-0.776	9.405	-64.49	-30.22	-94.712	-12.420	3.928
9	169.90	220.000	0.233	0.007	-64.49	-0.29	-64.780	-0.464	0.655
10	173.20	261.000	0.166	0.086	-64.49	-3.59	-68.081	-1.271	0.725
11	169.11	209.000	0.259	0.000	-58.04	0.54	-57.502	-0.148	0.583

Data Preparation - Loading of Light Aircraft

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Pressure distribution tables in different sections of the wing for one of the various flight conditions and in one flight section

Y=2450(mm)		
No.case	1	
X(%chord)	cpu	cpl
0	-0.6341	-0.482
0.004	-0.6341	-0.482
0.008	-0.6341	-0.482
0.012	-0.6341	-0.482
0.016	-0.6341	-0.482
0.02	-0.6341	-0.482
0.024	-0.6341	-0.482
0.028	-0.9316	0.2576
0.032	-1.2071	0.721
0.036	-1.3323	0.9494
0.04	-1.3293	0.9205
0.044	-1.3262	0.8916
0.048	-1.3231	0.8534
0.052	-1.3201	0.8089
0.056	-1.3073	0.7643
0.06	-1.2643	0.7197
0.064	-1.2214	0.6751
0.068	-1.2012	0.6446
0.072	-1.1952	0.6231
0.076	-1.1893	0.6015
0.08	-1.1834	0.5799
0.084	-1.1775	0.5583
0.088	-1.1715	0.5368
0.092	-1.1656	0.5153
0.096	-1.1597	0.4938
0.1	-1.1538	0.4723
0.104	-1.1382	0.4507
0.108	-1.1225	0.4292

Y=2450(mm)		
No.case	1	
X(%chord)	cpu	cpl
0	-0.6341	-0.482
0.004	-0.6341	-0.482
0.008	-0.6341	-0.482
0.012	-0.6341	-0.482
0.016	-0.6341	-0.482
0.02	-0.6341	-0.482
0.024	-0.6341	-0.482
0.028	-0.9316	0.2576
0.032	-1.2071	0.721
0.036	-1.3323	0.9494
0.04	-1.3293	0.9205
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0.072	-1.1952	0.6231
0.076	-1.1893	0.6015
0.08	-1.1834	0.5799
0.084	-1.1775	0.5583
0.088	-1.1715	0.5368
0.092	-1.1656	0.5153

No.case	1	
X(%chord)	cpu	cpl
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0.004	-0.6341	-0.482
0.008	-0.6341	-0.482
0.012	-0.6341	-0.482
0.016	-0.6341	-0.482
0.02	-0.6341	-0.482
0.024	-0.6341	-0.482
0.028	-0.9316	0.2576
0.032	-1.2071	0.721
0.036	-1.3323	0.9494
0.04	-1.3293	0.9205
0.044	-1.3262	0.8916
0.048	-1.3231	0.8534
0.052	-1.3201	0.8089
0.056	-1.3073	0.7643
0.06	-1.2643	0.7197
0.064	-1.2214	0.6751
0.068	-1.2012	0.6446
0.072	-1.1952	0.6231
0.076	-1.1893	0.6015
0.08	-1.1834	0.5799
0.084	-1.1775	0.5583
0.088	-1.1715	0.5368
0.092	-1.1656	0.5153
0.096	-1.1597	0.4938
0.1	-1.1538	0.4723

Data Preparation - Loading of Light Aircraft

Pressure distribution tables in different sections of the wing for one of the various flight conditions and in one flight section

Y=2450(mm)		
No.case	1	
X(%chord)	cpu	cpl
0.336	-0.9263	-0.087
0.34	-0.923	-0.092
0.344	-0.9198	-0.098
0.348	-0.9166	-0.103
0.352	-0.9134	-0.109
0.356	-0.9102	-0.115
0.36	-0.907	-0.12
0.364	-0.9021	-0.123
0.368	-0.8972	-0.127
0.372	-0.8923	-0.13
0.376	-0.8873	-0.133
0.38	-0.8824	-0.136
0.384	-0.8775	-0.139
0.388	-0.8726	-0.142
0.392	-0.8677	-0.145
0.396	-0.8628	-0.148
0.4	-0.8579	-0.152
0.404	-0.853	-0.155
0.408	-0.8481	-0.159
0.412	-0.8431	-0.162
0.416	-0.8382	-0.166
0.42	-0.8333	-0.169
0.424	-0.8284	-0.173
0.428	-0.8235	-0.176
0.432	-0.8183	-0.18
0.436	-0.8125	-0.183
0.44	-0.8067	-0.187
0.444	-0.8009	-0.19

Y=2450(mm)		
No.case	1	
X(%chord)	cpu	cpl
0.448	-0.7951	-0.194
0.452	-0.7893	-0.197
0.456	-0.7835	-0.201
0.46	-0.7775	-0.204
0.464	-0.7706	-0.204
0.468	-0.7636	-0.205
0.472	-0.7567	-0.205
0.476	-0.7497	-0.206
0.48	-0.7428	-0.206
0.484	-0.7358	-0.206
0.488	-0.7289	-0.207
0.492	-0.7219	-0.207
0.496	-0.715	-0.208
0.5	-0.708	-0.208
0.504	-0.701	-0.21
0.508	-0.6941	-0.212
0.512	-0.6871	-0.214
0.516	-0.6802	-0.216
0.52	-0.6732	-0.218
0.524	-0.6663	-0.22
0.528	-0.6593	-0.222
0.532	-0.652	-0.224
0.536	-0.6433	-0.226
0.54	-0.6346	-0.227
0.544	-0.6259	-0.229
0.548	-0.6171	-0.231
0.552	-0.6084	-0.233
0.556	-0.5997	-0.235

Y=2450(mm)		
No.case	1	
X(%chord)	cpu	cpl
0.56	-0.591	-0.237
0.564	-0.5847	-0.237
0.568	-0.5797	-0.237
0.572	-0.5747	-0.236
0.576	-0.5697	-0.235
0.58	-0.5647	-0.235
0.584	-0.5597	-0.234
0.588	-0.5547	-0.233
0.592	-0.5497	-0.233
0.596	-0.5447	-0.232
0.6	-0.5397	-0.231
0.604	-0.5347	-0.233
0.608	-0.5297	-0.236
0.612	-0.5247	-0.238
0.616	-0.5197	-0.241
0.62	-0.5147	-0.243
0.624	-0.5097	-0.246
0.628	-0.5047	-0.248
0.632	-0.4992	-0.251
0.636	-0.4928	-0.253
0.64	-0.4865	-0.255
0.644	-0.4801	-0.258
0.648	-0.4737	-0.26
0.652	-0.4673	-0.263
0.656	-0.4609	-0.265
0.66	-0.4545	-0.268
0.664	-0.4472	-0.264
0.668	-0.4397	-0.259

Data Preparation - Loading of Light Aircraft

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Pressure distribution tables in different sections of the wing for one of the various flight conditions and in one flight section

Y=2450(mm)		
No.case	1	
X(%chord)	cpu	cpl
0.672	-0.4321	-0.253
0.676	-0.4246	-0.248
0.68	-0.417	-0.243
0.684	-0.4095	-0.237
0.688	-0.402	-0.232
0.692	-0.3944	-0.227
0.696	-0.3869	-0.221
0.7	-0.3793	-0.22
0.704	-0.3718	-0.221
0.708	-0.3642	-0.221
0.712	-0.3567	-0.221
0.716	-0.3491	-0.221
0.72	-0.3416	-0.222
0.724	-0.3341	-0.222
0.728	-0.3233	-0.222
0.732	-0.312	-0.223
0.736	-0.3007	-0.223
0.74	-0.2894	-0.223
0.744	-0.2781	-0.224
0.748	-0.2668	-0.224
0.752	-0.2555	-0.224
0.756	-0.2488	-0.22
0.76	-0.2464	-0.212
0.764	-0.244	-0.203
0.768	-0.2416	-0.195
0.772	-0.2392	-0.186
0.776	-0.2369	-0.178
0.78	-0.2345	-0.169

Y=2450(mm)		
No.case	1	
X(%chord)	cpu	cpl
0.784	-0.2321	-0.161
0.788	-0.2297	-0.157
0.792	-0.2273	-0.154
0.796	-0.225	-0.151
0.8	-0.2226	-0.149
0.804	-0.2202	-0.146
0.808	-0.2178	-0.144
0.812	-0.2116	-0.141
0.816	-0.2038	-0.139
0.82	-0.196	-0.136
0.824	-0.1881	-0.134
0.828	-0.1803	-0.131
0.832	-0.1725	-0.128
0.836	-0.1647	-0.126
0.84	-0.1665	-0.121
0.844	-0.1693	-0.115
0.848	-0.1721	-0.109
0.852	-0.1749	-0.103
0.856	-0.1777	-0.098
0.86	-0.1804	-0.092
0.864	-0.1832	-0.088
0.868	-0.186	-0.085
0.872	-0.1888	-0.082
0.876	-0.1916	-0.08
0.88	-0.1944	-0.077
0.884	-0.1915	-0.074
0.888	-0.1863	-0.071
0.892	-0.1812	-0.068

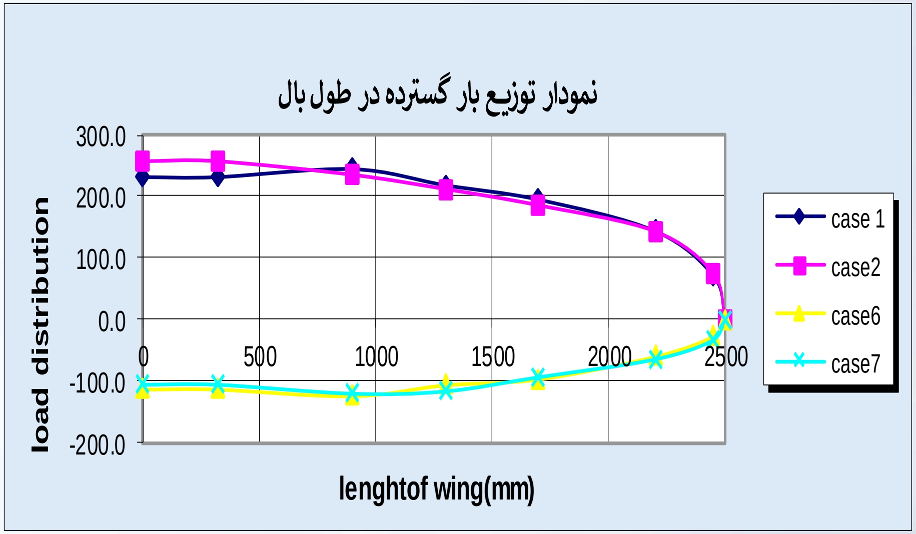
Y=2450(mm)		
No.case	1	
X(%chord)	cpu	cpl
0	-0.6341	-0.482
0.004	-0.6341	-0.482
0.008	-0.6341	-0.482
0.012	-0.6341	-0.482
0.016	-0.6341	-0.482
0.02	-0.6341	-0.482
0.024	-0.6341	-0.482
0.028	-0.9316	0.2576
0.032	-1.2071	0.721
0.036	-1.3323	0.9494
0.04	-1.3293	0.9205
0.044	-1.3262	0.8916
0.048	-1.3231	0.8534
0.052	-1.3201	0.8089
0.056	-1.3073	0.7643
0.06	-1.2643	0.7197
0.064	-1.2214	0.6751
0.068	-1.2012	0.6446
0.072	-1.1952	0.6231
0.076	-1.1893	0.6015
0.08	-1.1834	0.5799
0.084	-1.1775	0.5583
0.088	-1.1715	0.5368

Data Preparation - Loading of Light Aircraft

Distributed load table along the wing

No.case	1	2	6	7
M	*0.18*	*0.213*	0.213	0.147
n	*6*	*6*	-3	-3
Alpha(deg)	14.1	9.1	-9.4	16.2
de(deg)	-5.4	-3.58	3	5.4
y(mm)	h(kg/m)			
0	232.2	257.3	-113.1	-105.6
320	232.2	257.3	-113.1	-105.6
900	245.3	235.3	-123.9	-120.3
1300	219.0	212.1	-106.1	-116.5
1700	195.6	185.8	-96.8	-93.5
2200	144.3	143.5	-60.1	-64.4
2450	70.7	74.8	-27.0	-32.6
2500	0.0	0.0	0.0	0.0

Distributed load diagram along the wing



Data Preparation - Loading of Light Aircraft

Shear force table along the wing

No.case	*1*	*2*	*6*	*7*
M	*0.18*	*0.213*	0.213	0.147
n	*6*	*6*	-3	-3
Alpha(deg)	14.1	9.1	-9.4	16.2
de(deg)	-5.4	-3.58	3	5.4
y(mm)	q(kg)			
0	502.2	505.7	-242.3	-241.1
320	427.9	423.4	-206.1	-207.3
900	289.4	280.5	-137.4	-141.7
1300	196.5	191.1	-91.4	-94.4
1700	113.6	111.5	-50.8	-52.4
2200	28.6	29.2	-11.6	-12.9
2450	1.8	1.9	-0.7	-0.8
2500	0.0	0.0	0.0	0.0

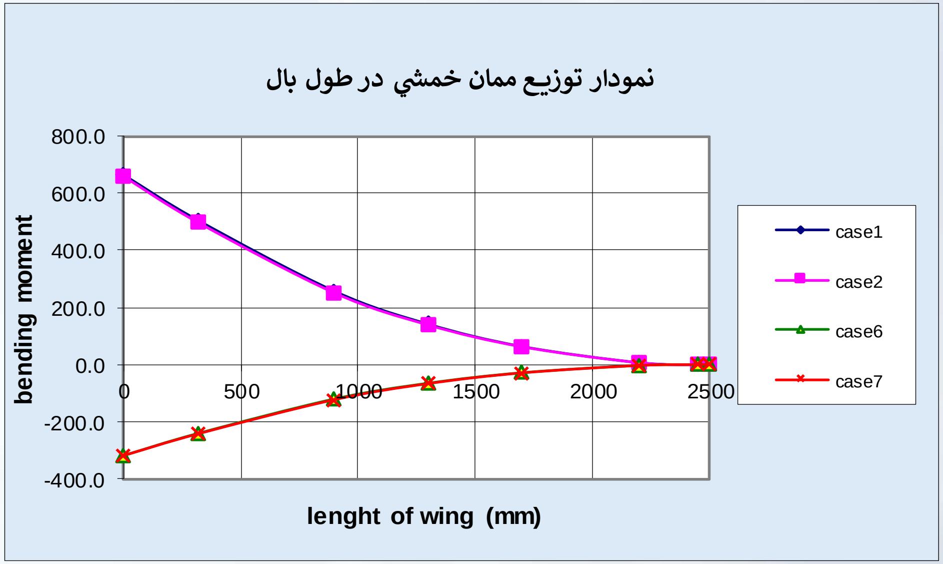
Shear force distribution diagram along the wing

Data Preparation - Loading of Light Aircraft

Bending moment table along the wing

No.case	1	2	6	7
M	*0.18*	*0.213*	0.213	0.147
n	*6*	*6*	-3	-3
Alpha(deg)	14.1	9.1	-9.4	16.2
de(deg)	-5.4	-3.58	3	5.4
y(mm)	Mb(kg.m)			
0	667.3	659.2	-316.9	-321.3
320	506.6	497.3	-239.3	-244.1
900	258.4	251.8	-119.8	-123.9
1300	142.7	139.6	-64.9	-67.2
1700	64.1	63.1	-28.3	-29.5
2200	7.2	7.4	-2.9	-3.3
2450	0.1	0.1	0.0	0.0
2500	0.0	0.0	0.0	0.0

Bending moment distribution diagram along the wing

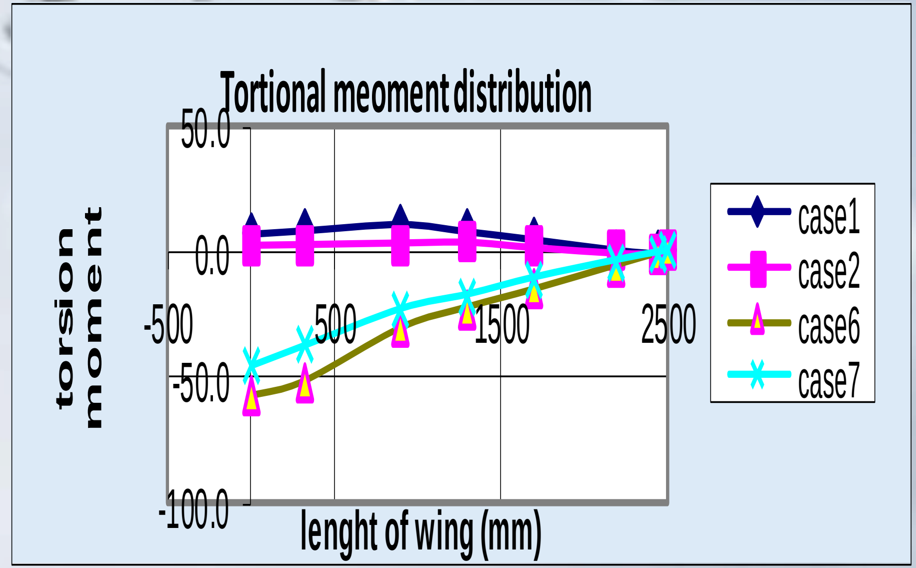


Data Preparation - Loading of Light Aircraft

Torsional moment table along the wing

No.case	*1*	*2*	*6*	*7*
M	*0.18*	*0.213*	0.213	0.147
n	*6*	*6*	-3	-3
Alpha(deg)	14.1	9.1	-9.4	16.2
de(deg)	-5.4	-3.58	3	5.4
y(mm)	Mt(kg.m)			
0	7.8	2.6	-57.3	-44.9
320	9.1	2.8	-51.4	-37.0
900	11.5	3.3	-30.4	-22.6
1300	8.7	3.5	-22.3	-17.1
1700	5.6	1.8	-15.2	-10.4
2200	1.4	0.1	-5.6	-3.6
2450	0.0	-0.1	-0.9	-0.5
2500	0.0	0.0	0.0	0.0

Torsional moment distribution diagram along the wing



Model Selection and Training

Algorithm Selection: The rationale behind selecting specific ML algorithms, such as Gradient Boosting, is based on their ability to capture non-linear relationships. Gradient Boosting, for instance, is advantageous due to its high accuracy and robustness in handling complex interactions between features.

Hyperparameter Tuning: Hyperparameter tuning techniques, such as Grid Search, optimize model performance. For example, Grid Search was used to fine-tune the Gradient Boosting model, enhancing prediction accuracy.

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Machine Learning Predictions for Various Flight States

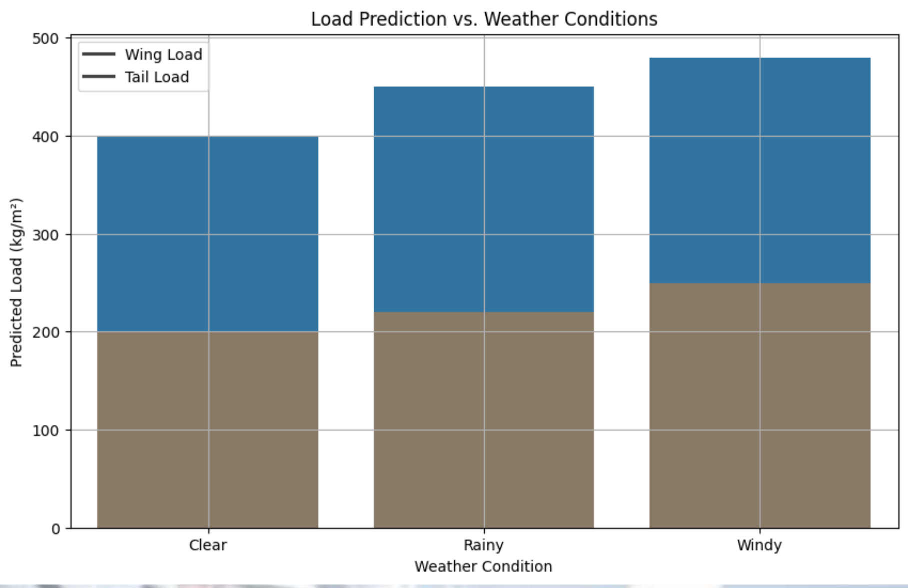
Feature	Description	Value Range
Wing Loading	Load per unit area on the wing	300 - 900 kg/m²
Tail Loading	Load per unit area on the tail	100 - 500 kg/m²
Temperature	Ambient temperature	-20°C to 50°C
Weather Condition	Type of weather (clear, rainy)	Clear, Rainy, Windy
Flight Condition	Specific flight scenarios	Takeoff, Cruise, Landing
Altitude	Altitude of the flight	0 - 40,000 ft
Wind Speed	Wind speed during flight	0 - 100 km/h

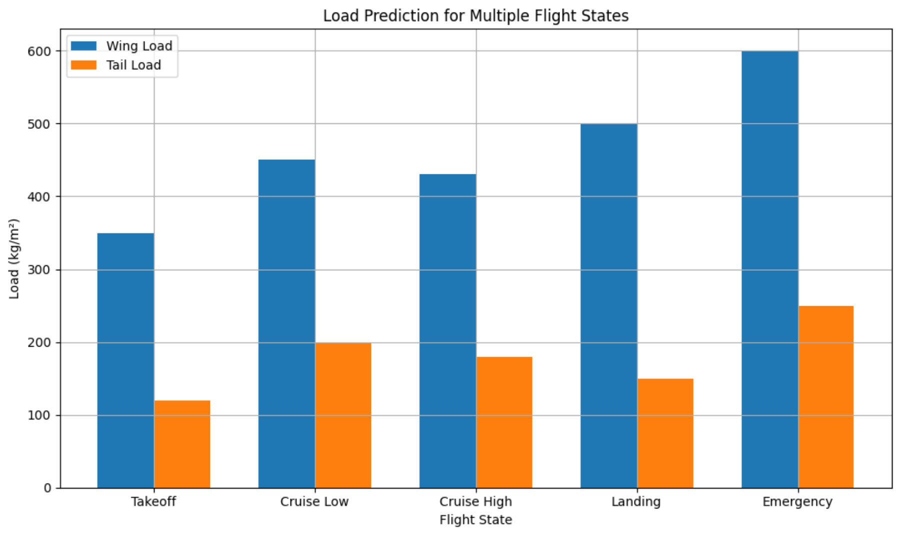
Flight State	Temperature (°C)	Weather Condition	Load Factor (n)	Wing Load (kg/m²)	Tail Load (kg/m²)
Takeoff	25	Clear	4	350	120
Cruise Low	15	Windy	1.5	450	200
Cruise High	-10	Clear	1.2	430	180
Landing	30	Rainy	3	500	150
Emergency	20	Windy	2.8	600	250
...	...	...	...	...	...
State 2000	40	Windy	3.5	700	300

Model Evaluation - Graphical Representation

Graph 1: Load Prediction vs. Weather Conditions

This bar chart compares the predicted loads on the wing and tail under different weather conditions. It highlights how various environmental factors can impact the load distribution on the aircraft.





Graph 2: Load Prediction for Multiple Flight States

This bar chart shows the predicted loads on the wing and tail for various flight states. It helps visualize the differences in load distribution during different phases of flight, including takeoff, cruise, landing, and emergency maneuvers.

Model Training and Evaluation

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The dataset was split into training and testing sets to evaluate model performance effectively.

Features were standardized to ensure all models received data on a similar scale.

Each model was trained using the scaled training data.

Models evaluated include Linear Regression, Ridge Regression, Lasso Regression, Random Forest, Gradient Boosting, Support Vector Regressor, XGBoost, and LightGBM.

Model Evaluation

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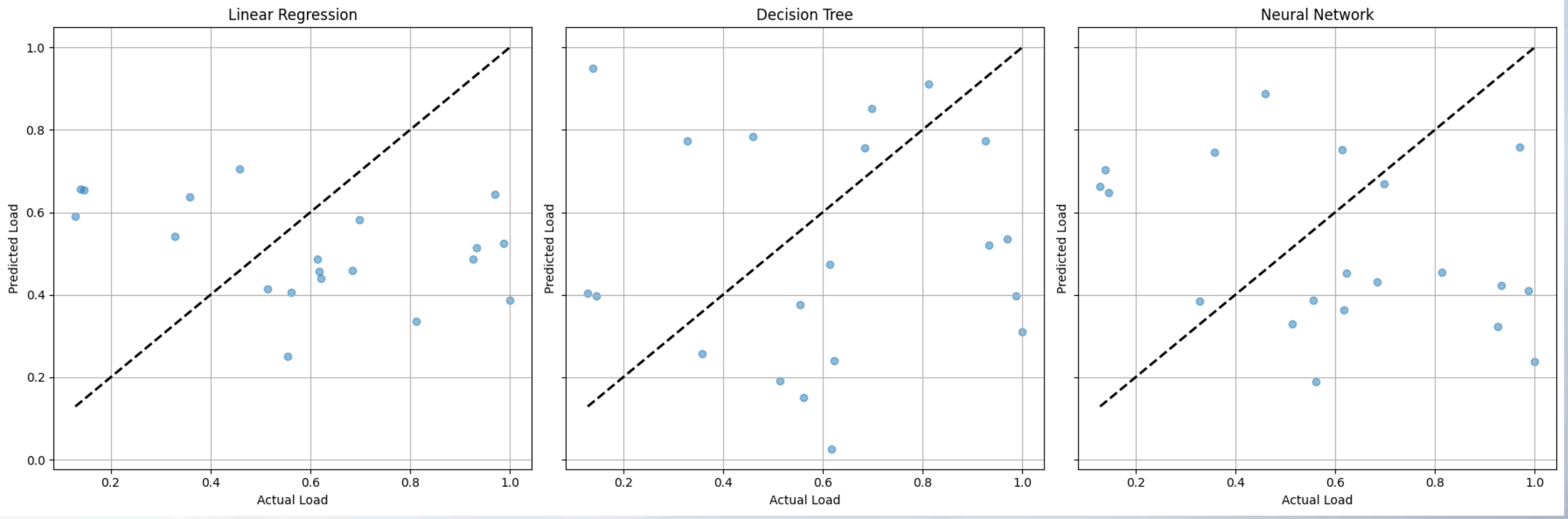
Performance metrics (MSE and R-squared) for each model.

Model	Mean Squared Error	R-squared
Linear Regression	0.0028	0.918
Ridge Regression	0.0029	0.917
Lasso Regression	0.0032	0.913
Random Forest	0.0019	0.941
Gradient Boosting	0.0018	0.945
SVR	0.0021	0.937
XGBoost	0.0017	0.948
LightGBM	0.0018	0.946

Scatter Plot: Actual vs Predicted



Hyperparameter Tuning and Final Model Performance

- Grid Search for Gradient Boosting to find the optimal hyperparameters.
- Best model parameters and performance metrics.
- Summary of the best performing model (Gradient Boosting with tuned hyperparameters).
- Final performance metrics (MSE and R-squared).

Model	Mean Squared Error	R-squared
Gradient Boosting (Tuned)	0.0015	0.950

Conclusion and Inference on Load Analysis of Light Aircraft

- **Generally, every aircraft uses the horizontal tail and elevator control surface to maintain balance and perform maneuvers in the vertical plane. The loading of the horizontal tail is examined in all flight conditions.**

- **The loads applied to the horizontal tail are determined in two forms: balancing loads and maneuvering loads. Balancing loads are specified in the aircraft balance section.**

- **Loading calculations are performed at different altitudes and for takeoff and landing conditions. For each flight envelope, different flight conditions are considered based on maneuvering characteristics, and after performing the necessary calculations, the critical loads are used in structural analysis.**

Conclusion and Inference on Load Analysis of Light Aircraft

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Successful Application of ML Techniques:

Demonstrated the successful application of machine learning techniques for predicting and optimizing aircraft load distribution.

Significant improvements in prediction accuracy, particularly with the Gradient Boosting model after hyperparameter tuning.

Key Achievements:

Conducted comprehensive analysis across all aircraft parts, including the wing, tail assembly, and fuselage.

Utilized advanced prediction models and simulations to reduce reliance on expensive wind tunnel tests.

Successfully created and achieved flight for the Light aircraft, validating the efficacy of our predictive models and testing protocols.

Thank you for your attention!

Sara Khosravi

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