AI-Driven Pre-Design Predictions of a 90 Passenger Hybrid-Electric Aircraft

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Outline

1. Problem framing
2. Method
3. Results
4. Conclusions

Problem Framing

Hybrid-Electric Aircraft Needed!

- The RETAS project[1] needs aircraft models.
  - A 90-passenger hybrid electric model was needed based on demand predictions[2].
    - This is a small "spin-off"

RETAS

vti

Network level analysis for Scandinavia of future airplanes.

Needs

Aircraft Models

The Aircraft Conceptual Design Process

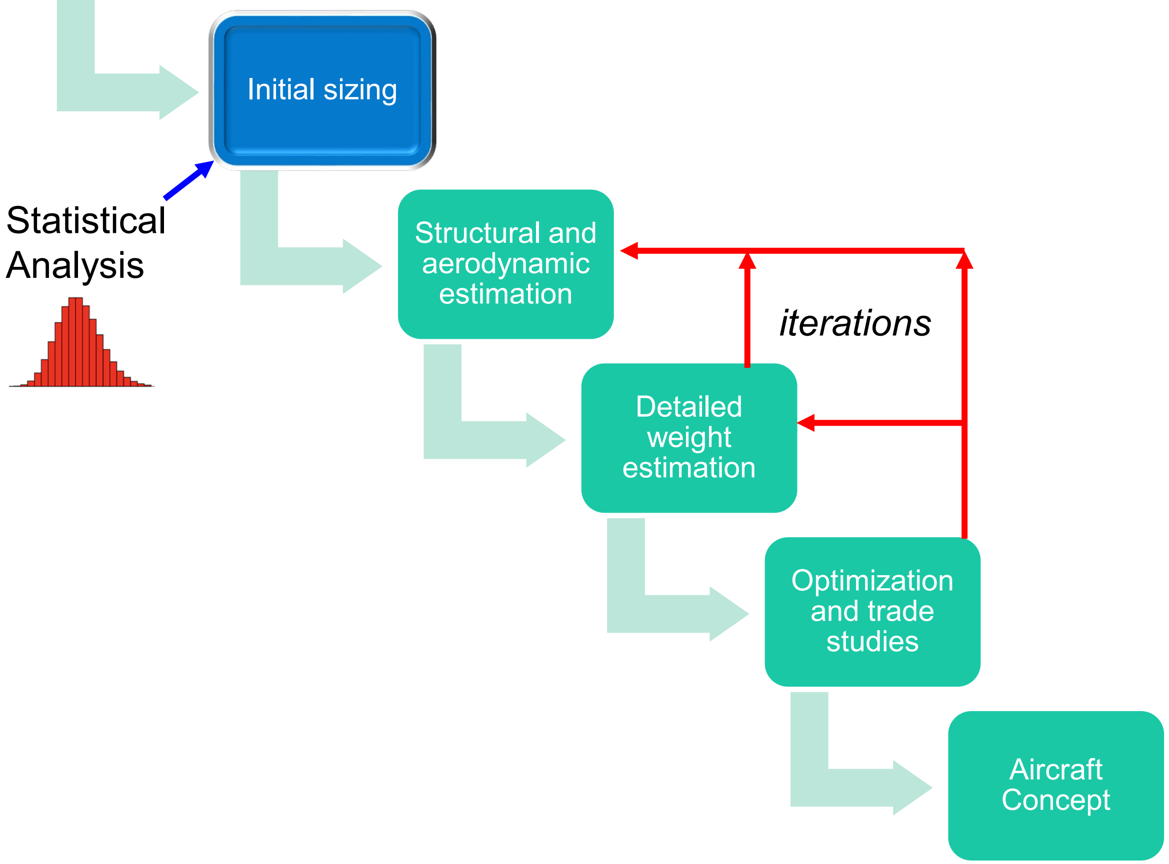
Top Level Requirements (given)

How much weight do you want to transport and where.

Payload: **Passengers** and cargo

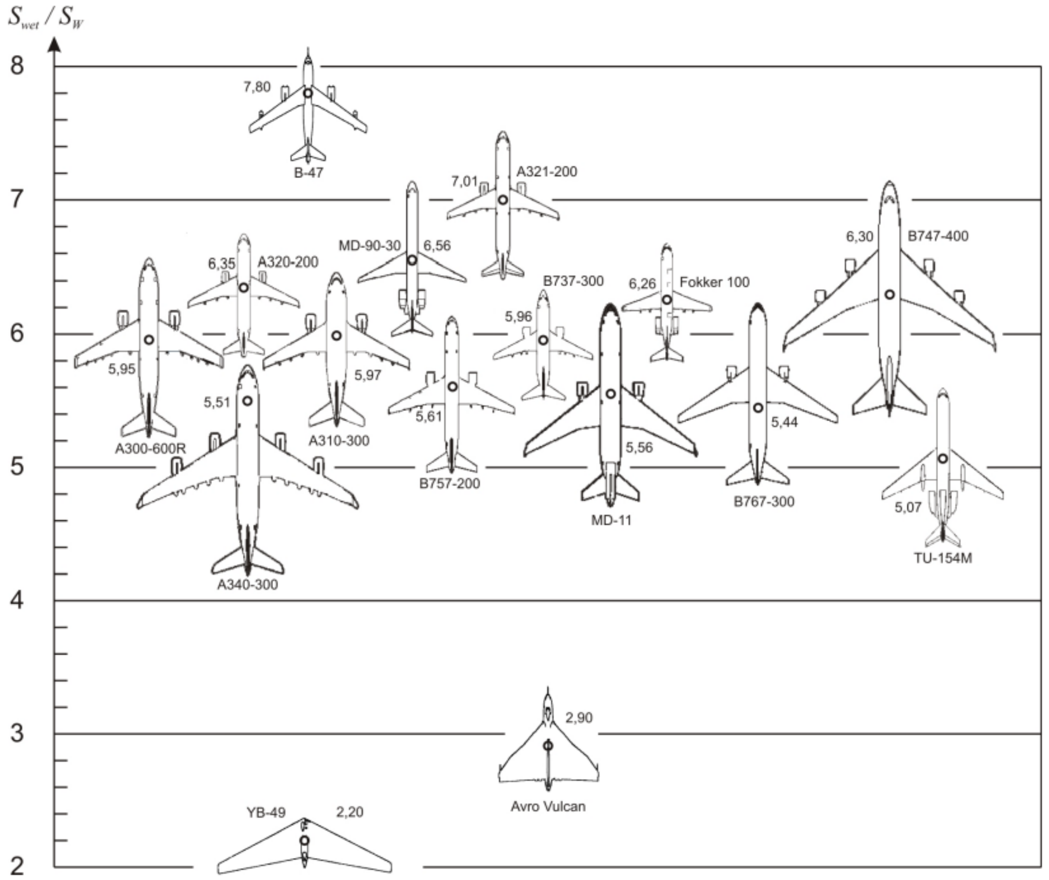
Range: Defined by battery technology (for hybrid-electric aircraft)

- Payload is given, range is to be determined.
- ***Your iterative design process must start somewhere.***
  - A statistical analysis gives you an educated guess.



Statistics on available designs

- Numerous statistics available based on existing aircraft
  - Just search it on a graph!
  - But what if the design searched for does not exist?



Aircraft plan forms and their relative wetted area.[3]

Electrified Aircraft Concepts Database

- Multiple concepts have been proposed in Academia & Industry.
- Creation of a 52 airplane database
- Data is not clean or complete
  - A conventional statistical analysis was performed

Hybrid-electric aircraft concept.[4]

Number	Model	Manufacturer / Designer	Propulsion	Type	Certification sought	nPAX	OEM [kg]	MTOM [kg]	Payload [kg]	Fuel Mass [kg]	Battery Mass [kg]	Battery Mass Fraction	Wingspan [m]	Wing area [m2]	MAC [m]	Aspect Ratio [ ]	Wing loading [kg/m2]
1	AEA-800	MIT	Full Electric	Air Transport	CS-25	180		109000	17500	0	48000	0.440	36	125.6	3.49	10.3	868
2	Volt Air	Airbus	Full Electric	Air Transport	CS-25	33	31000	33000		0							
3	Wright Spirit	Wright Electric	Full Electric	Air Transport	CS-25	100							26.34	77.3	2.935	9.0	0
4	A320-200PHE	TRADE	Hybrid-electric	Air Transport	CS-25	150		77000					33.91	122.4			644
5	A320neoPHE	TU DELFT	Hybrid-electric	Air Transport	CS-25	150		79000					35.8	122.6			644
6	ATR-72HE	TU Delft	Hybrid-electric	Air Transport	CS-25	70	13500	28500	7500	1400	4700	0.165	30.1	75.7	2.51	12.0	376
7	BHL A320PHE	Bauhaus Luftfahrt	Hybrid-electric	Air Transport	CS-25	180	42267.13	74023	18370	4655	8734.714	0.118	38.2	115.0			644
8	E-fan X	Airbus	Hybrid-electric	Air Transport	CS-25	70		38400		0	2000	0.052	26.34	77.3	2.93	9.0	497
9	ES-19	Heart Aerospace	Hybrid-electric	Air Transport	CS-25	19		8600	475		1600	0.186	32				
10	EVE	Georgia Tech	Hybrid-electric	Air Transport	CS-25	150	11339	69126			10205	0.148	50	137.2	2.744	18.2	504
11	PEGASUS	NASA	Hybrid-electric	Air Transport	CS-25	48		18143			5897	0.325	24.57	54.5	2.22	11.1	333
12	Refined SUGAR N+4	UTRC	Hybrid-electric	Air Transport	CS-25	154		61875		12026	9745	0.157		126.0		9.5	491
13	REG-C	NLR	Hybrid-electric	Air Transport	CS-25	40		21300			3600	0.169	24.57	43.2	1.76	14.0	493
14	REG-R	NLR	Hybrid-electric	Air Transport	CS-25	40		22641	6115		3070	0.136	30	65.6	2.19	13.7	345
15	STARC-ABL	NASA	Hybrid-electric	Air Transport	CS-25	150	36505	60495		8777		0.000	36	105.0	2.92	12.3	576
16	Sugar VOLT	Boeing	Hybrid-electric	Air Transport	CS-25	154	40280	68040		6667	7121	0.177	50	137.2	2.74	18.2	496
17	CENTRELINE	Bauhaus Luftfahrt	Turboelectric	Air Transport	CS-25	340		229000			0	0.000	65				644

What would have happened if I had just asked ChatGPT?

Usage of AI in pre-design studies and its comparison to conventional statistical methods

Method

What are we searching for?

- Configuration-independent design parameters

Mass

How heavy?

$$mass$$

~ 0.0005

~ 560,000

Units: kg

Wing Loading

How much mass per wing area?

$$\frac{mass}{wing\ area}$$

~ 0.1

~ 633

Units: kg/m2

Power Loading

How much propulsive power per kg?

$$\frac{power}{mass}$$

~ 0.14

~ 1.1

Units: kW/kg

Battery Mass Fraction

How much of the vehicle is battery?

$$\frac{mass_{battery}}{mass_{total}}$$

~ 0.25

Units: -

Conventional Statistics Methods

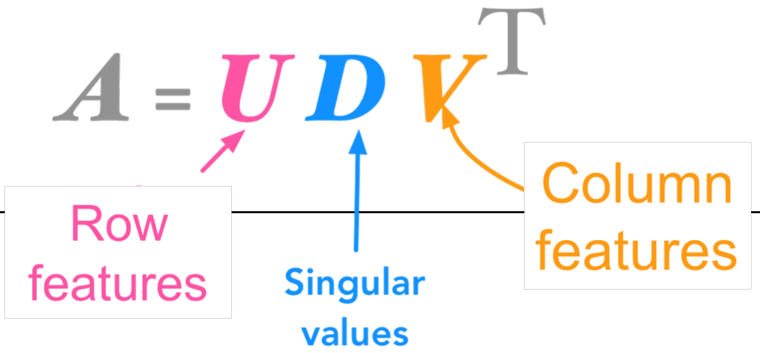
Linear Regression

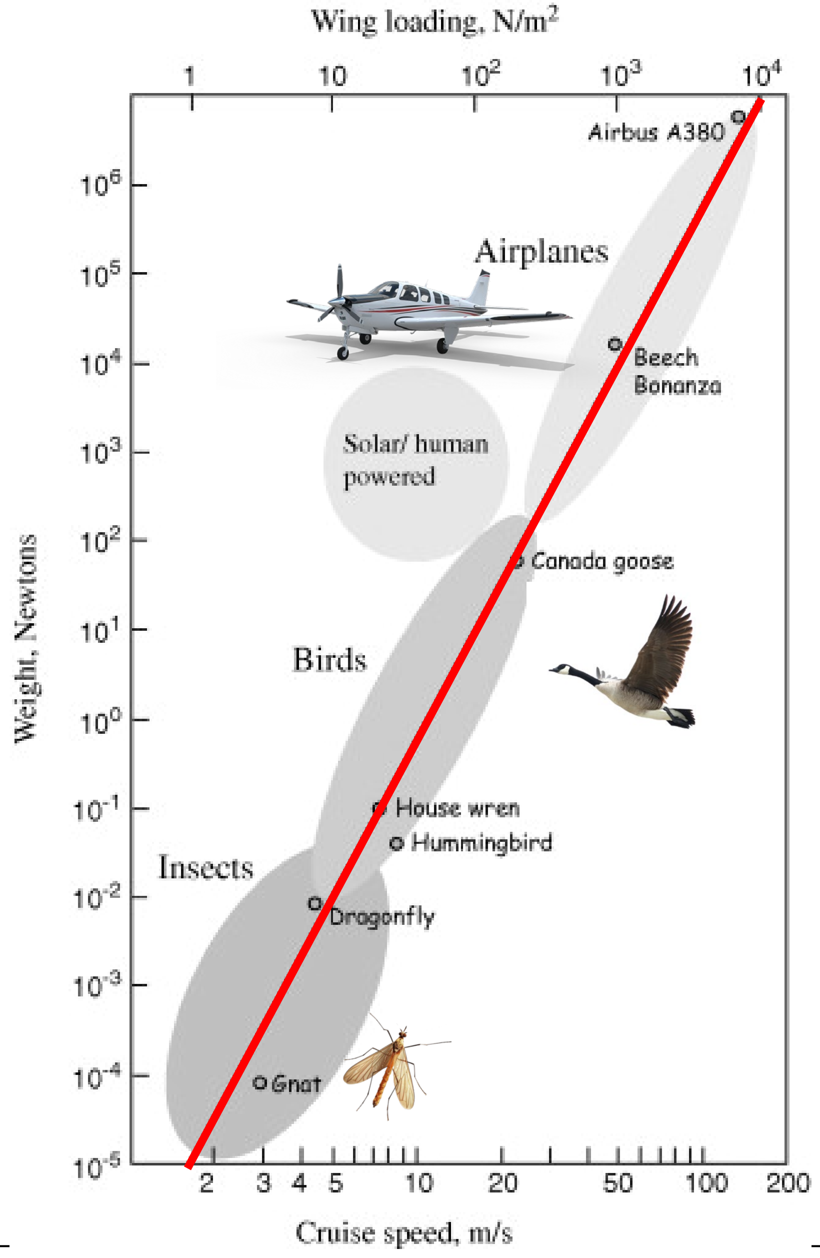
A linear approximation was applied to nPax and the searched variables.

-Logarithmic scale was used for better linearization

Singular Variable Decomposition

Only a few parameters can be used to represent what appears to be complex relations[6]



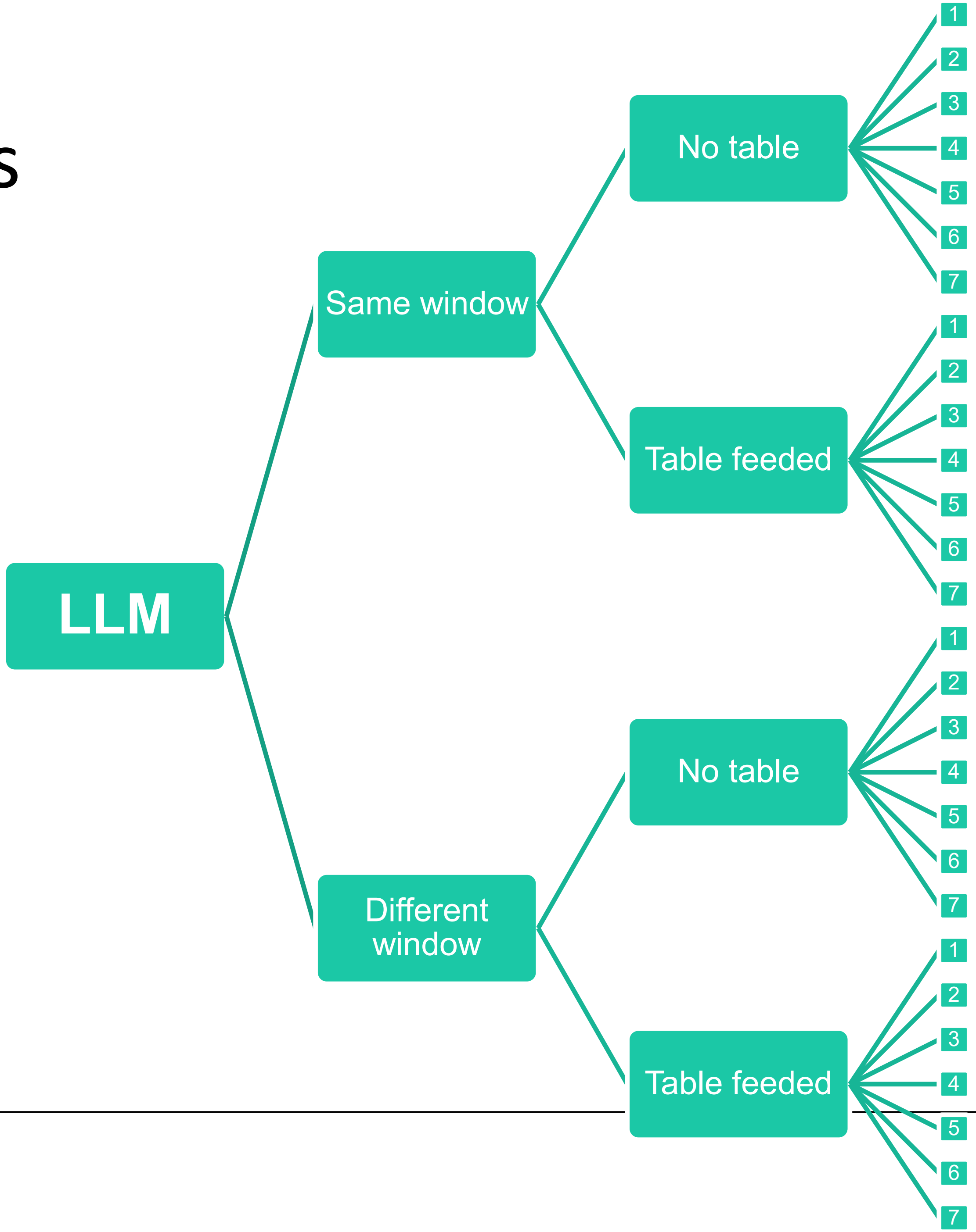


The Great Flight Diagram[5]

Different question strategies

Since answers are not deterministic, for each LLM:

- Questions (always the same) were asked sharing or not the table, in the same or in different windows.
  - 7 questions for each strategy



The question (always the same):

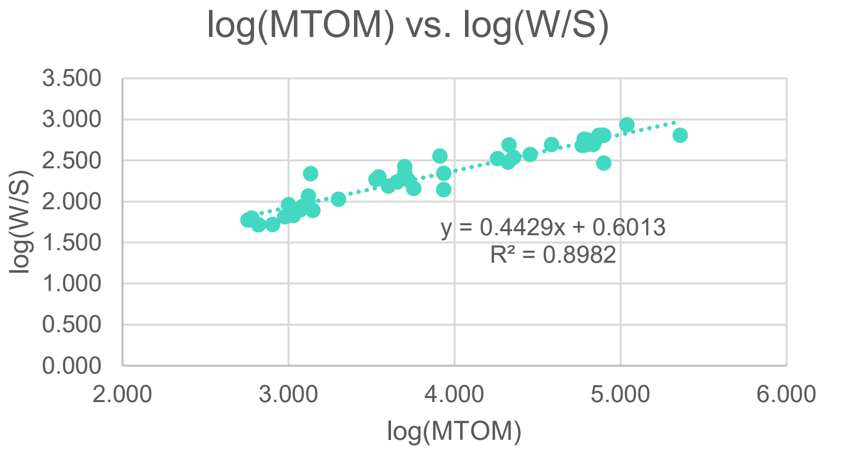
Give me the estimation for MTOM (in kg), cruise speed (in knots), Wing loading (in kg/m2), power to weight ratio (in kW/kg) and battery mass fraction for a HYBRID-ELECTRIC 90 PASSENGER AIRCRAFT

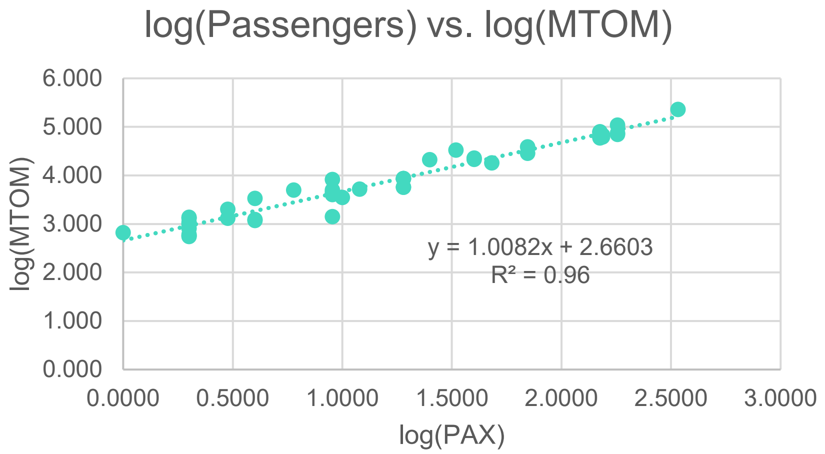
Based on this table and your own knowledge, give me the estimation for MTOM (in kg), cruise speed (in knots), Wing loading (in kg/m2), power to weight ratio (in kW/kg) and battery mass fraction for a HYBRID-ELECTRIC 90 PASSENGER AIRCRAFT

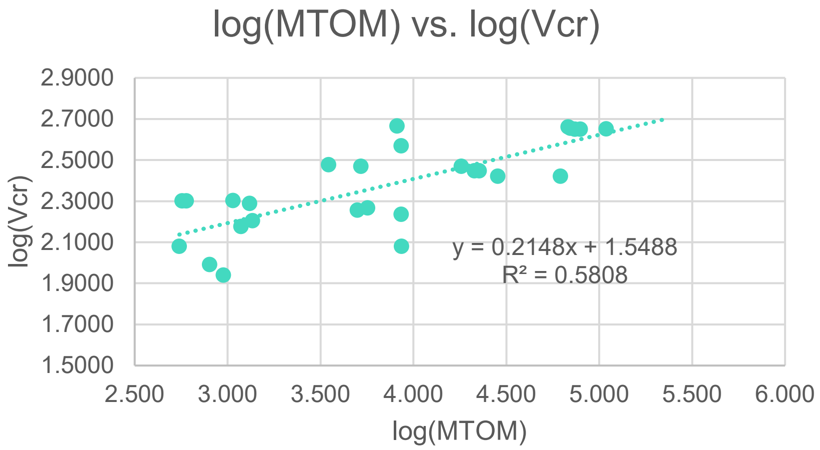
Results

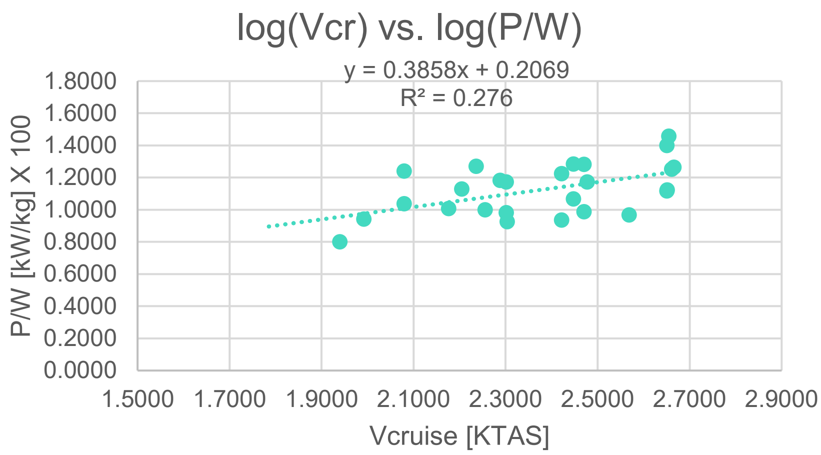
Linear Regression

- R^2 coefficient varied from 0.96 to 0.276.
- Went from nPAX→MTOM→(W/S)→(P/W)→BMF





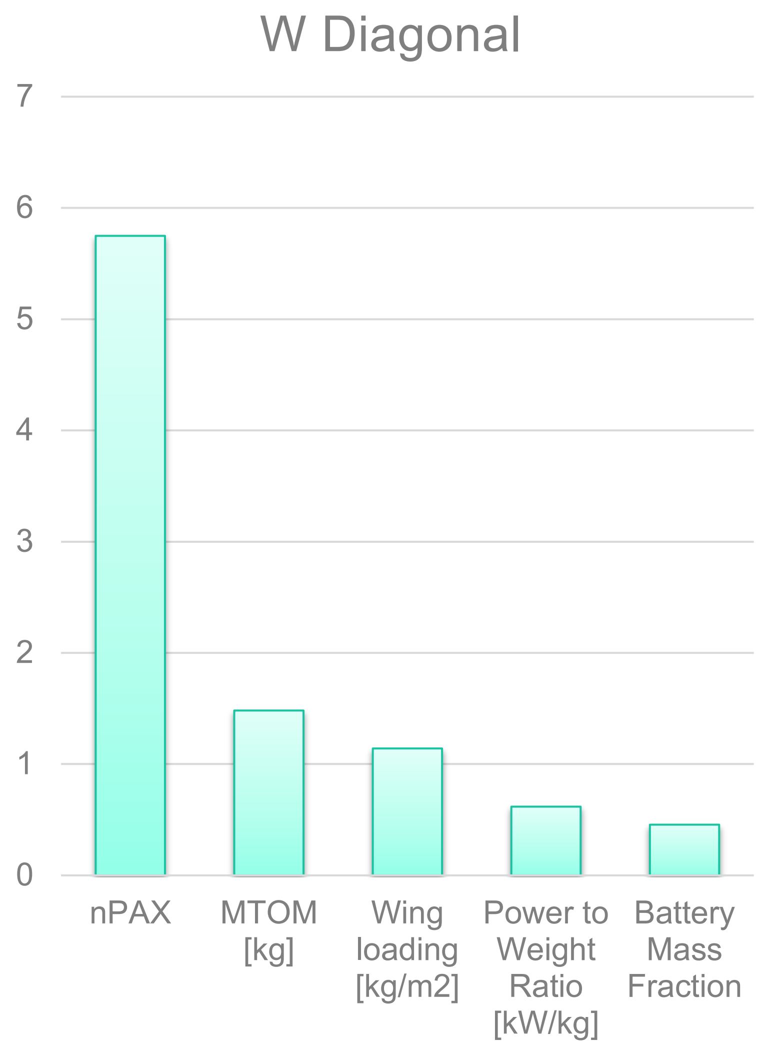




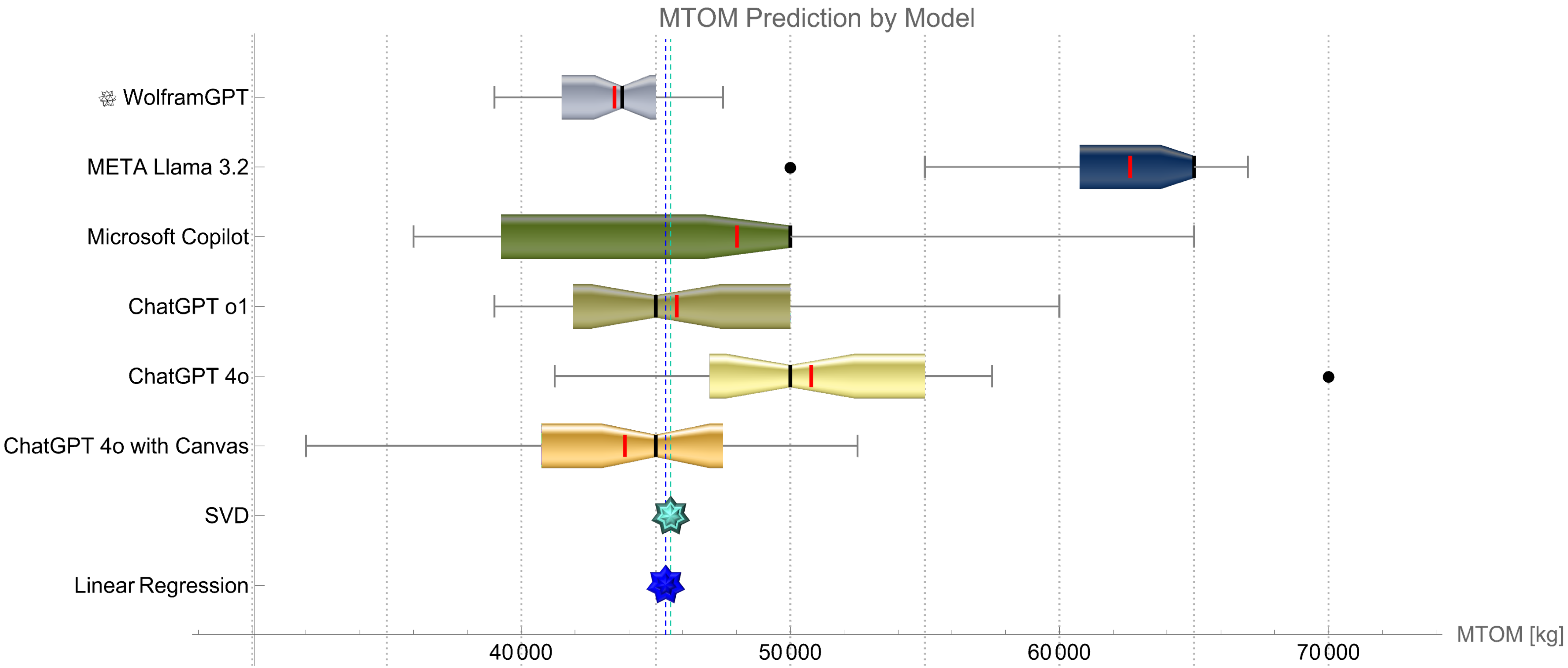
Singular Variable Decomposition (SVD)

- Aircraft dataset reduced from 52 to 31
- Number of passengers had the highest weight in the W-Diagonal.
  - Not absurd to predict other parameters from it.
  - All other SVD variables set to zero.

	Rel error	ATR-72HE	Estimate	Adjusted	Result	Average						SVD variables	w-diagonal	residual
nPAX	0.00	90.00	90.00	1.95	1.06	0.89	-0.691	0.111	-0.034	0.065	0.002	-1.54	5.75	0.89
MTOM [kg]	0.58	28500.00	45076.26	4.65	1.05	3.61	-0.681	-0.050	-0.002	-0.066	-0.034	0.00	1.48	0.17
Wing loading [kg/m2]	0.42	376.49	535.62	2.73	0.52	2.21	-0.339	-0.118	0.015	-0.008	0.068	0.00	1.14	0.12
Power to Weight Ratio [kW/kg]	0.01	0.17	0.17	-0.77	0.09	-0.86	-0.059	-0.181	0.070	0.059	-0.030	0.00	0.62	0.11
Battery Mass Fraction	0.03	0.16	0.17	-0.77	-0.13	-0.64	0.083	-0.096	-0.189	0.010	-0.006	0.00	0.46	0.09



Maximum Take-Off Mass



Median Mean

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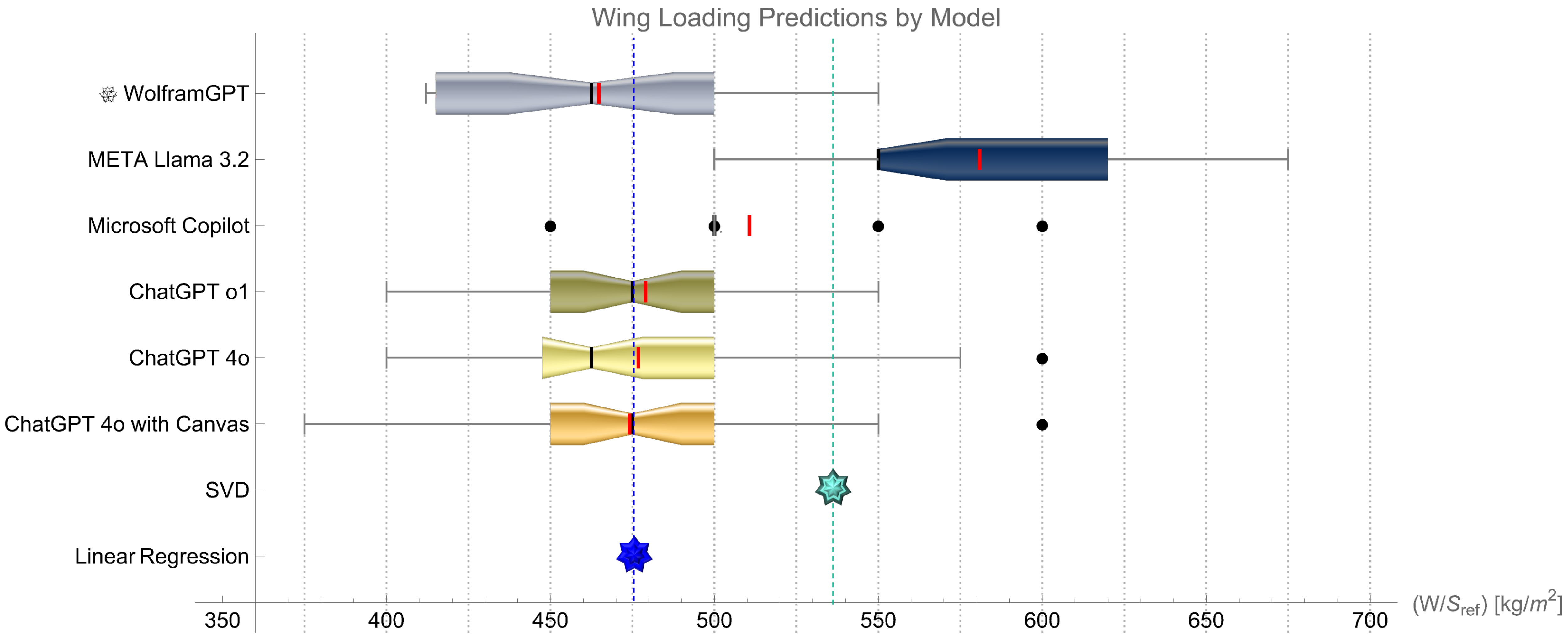
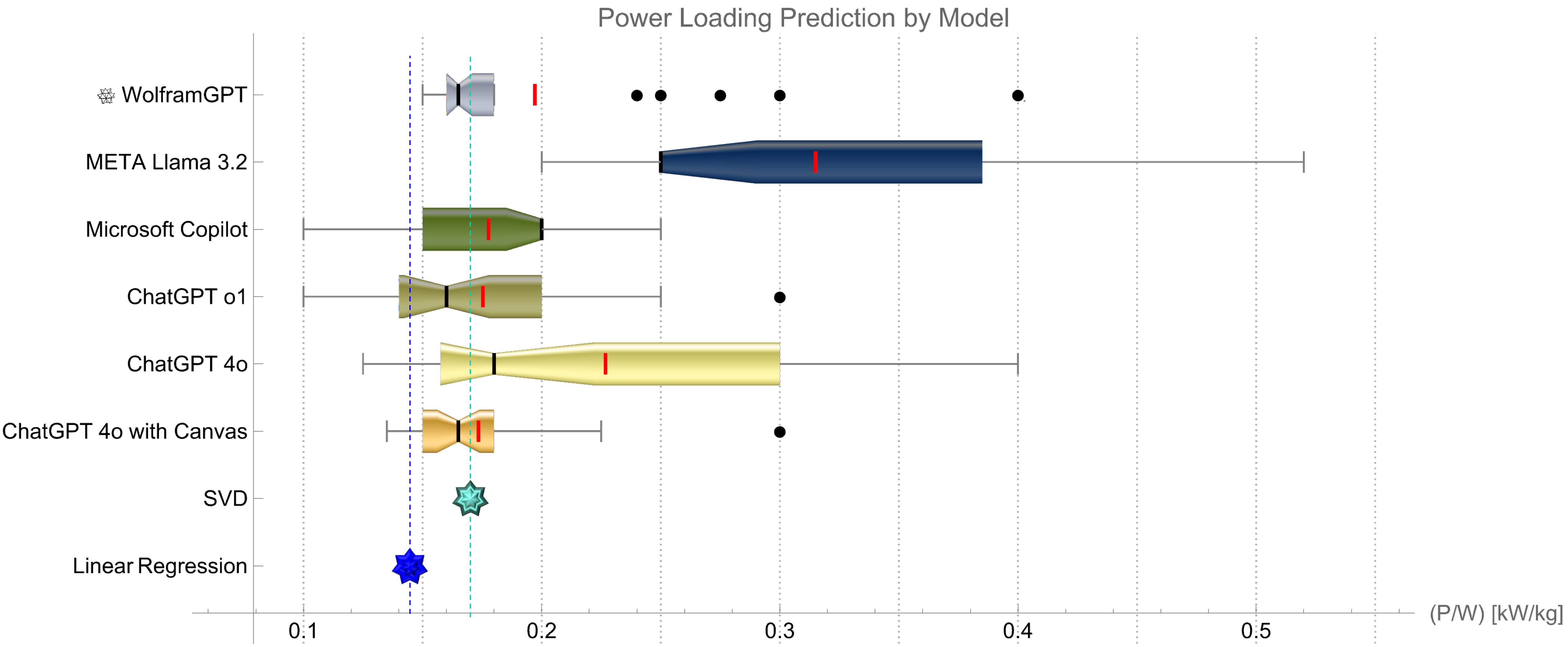
Wing Loading

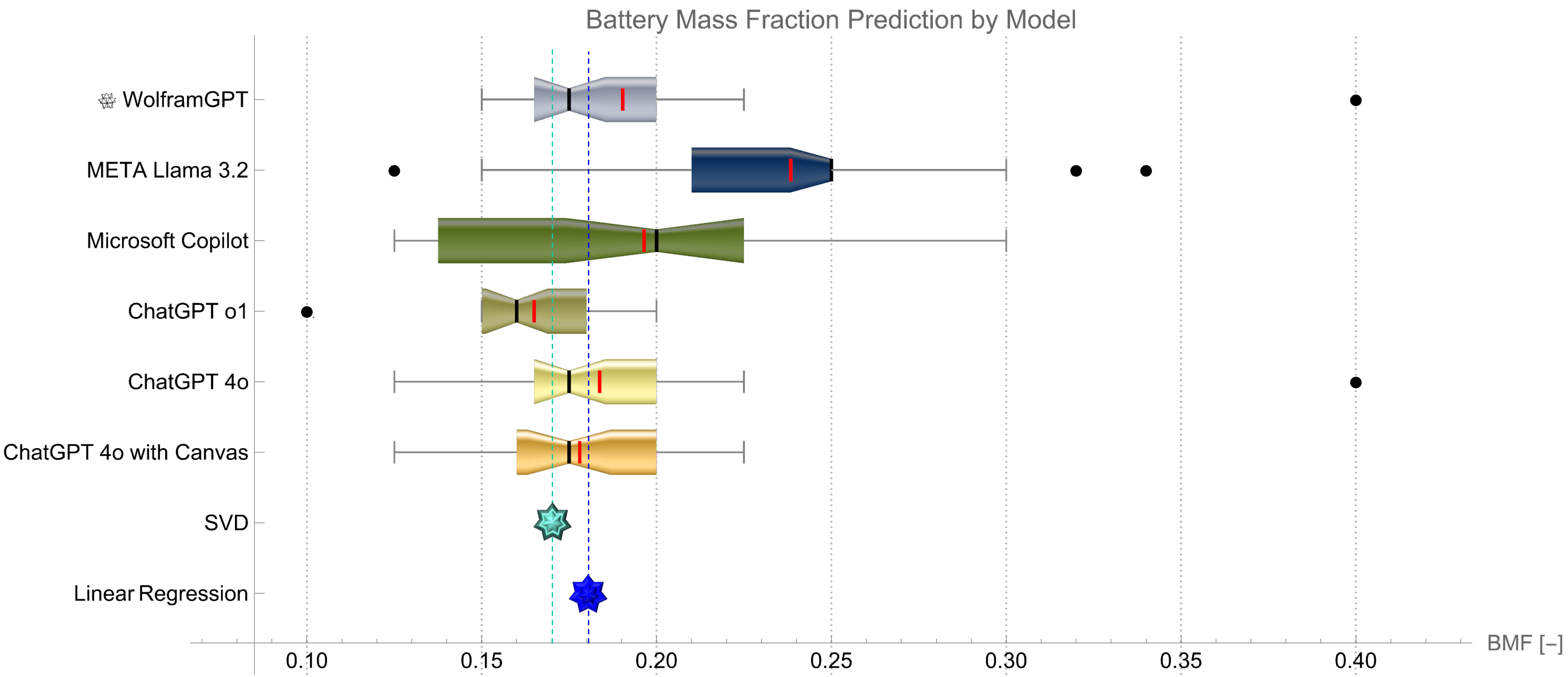


Power Loading



Median Mean

Battery Mass Fraction

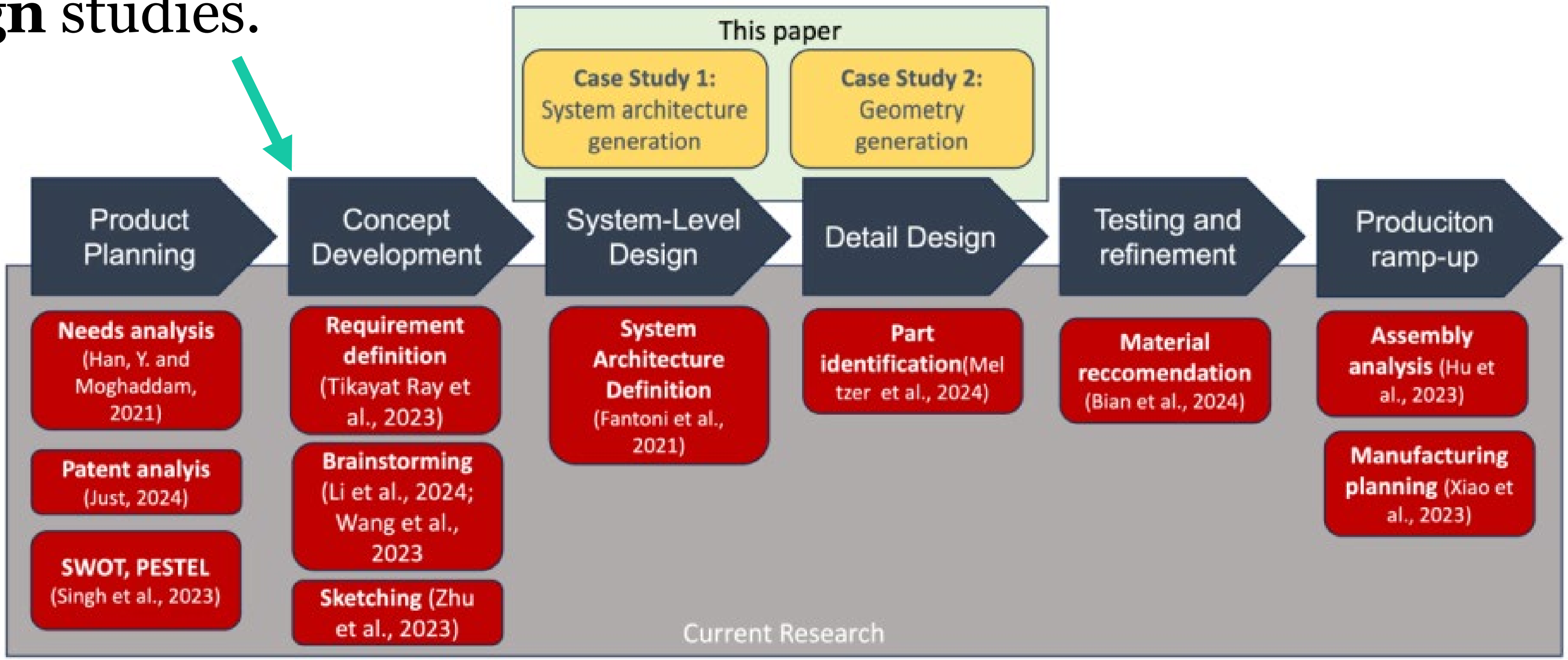


Median Mean

Conclusions

Conclusions

- AI was not used for inspiration[9] nor as active decision maker[10], but rather **as an interpolator/ extrapolator** (of not easily available data), **complementing statistical analysis**.
  - Useful in **pre-design** studies.



Current applications of LLMs in Product Design Activities, mapped alongside a generic development process.[11]

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