Hochschule für Angewandte Wissenschaften Hamburg
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AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

Comparing Modes of Transportation with an Improved Karman-Gabrielli Diagram

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Abstract

Purpose – To find, how passengers and freight transport efficiency depends on vehicle cruise speed. Based on the Karman-Gabrielli Diagram, four new diagrams are investigated. Plotted is a) the lift-to-drag ratio (weight-to-drag ratio) versus cruise speed. b) Vehicle weight is replaced by the weight of the payload. c) Plotted is the inverse of energy consumption per payload and range versus cruise speed. d) Energy consumption is replaced by primary energy.

Methodology – For each of the four new diagrams and for each considered means of transport, the governing equations are derived or obtained from literature. Data is collected and the diagrams are plotted. Results are discussed based on new figures of merit visualized in the form of straight iso-lines in the log-log plot. With normal axis the straight lines turn into a typical Pareto fronts.

Findings – Faster cruise speed of a vehicle is associated with reduced efficiency. More meaningful results are obtained if vehicle weight is replaced by the weight of the payload. Even better, if energy consumption is used or primary energy consumption compared to a slower vehicle. Freight ships are the best in fuel economy. The best compromise between fuel consumption and speed may be achieved by the hyperloop.

Research limitations – This paper includes only a selection of vehicles from each category due to limited data accessibility.

Practical implications – The Karman-Gabrielli Diagrams enable transportation users to make decisions regarding the most suitable mode of transport, considering various factors such as speed, economy, and environmental impact.

Originality – This seems to be the first report that extends the Karman-Gabrielli Diagram in such a way and proposes new transport figures of merit.

Table of Content

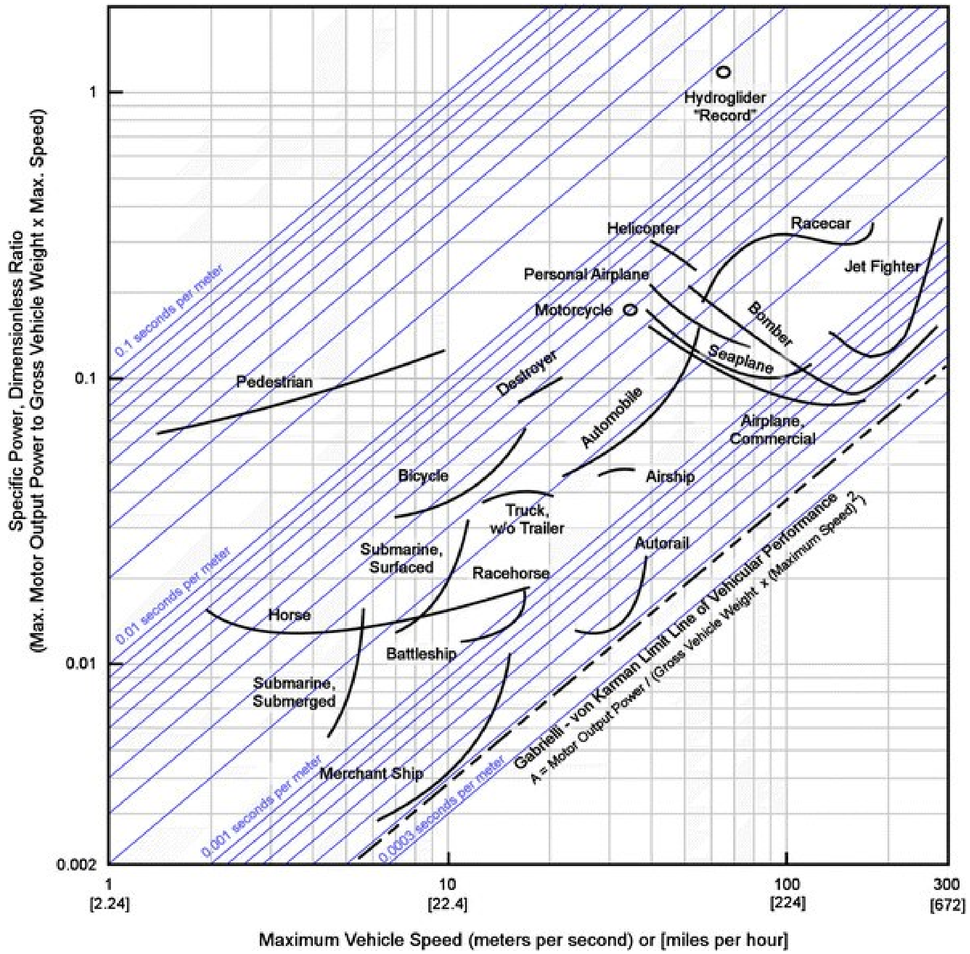
Introduction

OBJECTIVES

- The purpose of this paper is to discuss **"What price speed?"**, so that the analysis of the carrying capacity of the vehicle and its energy consumption shall be performed.
- The original KG diagram shall be improved, where lift over drag ratio shall be utilized in place of specific resistance, and cruising speed is used in place of maximum speed.
- This paper will also present several diagrams:
  - New KG Diagram
  - New KG Diagram with respect to payload mass
  - Inverse of primary energy consumption per payload and range
- For the diagrams, the transport figure of merit in terms of lift over drag a_{LD} and primary energy a_E shall be performed.

Karman-Gabrielli Diagram

The Original Karman-Gabrielli Diagram



The original Karman-Gabrielli Graph (Transcossi 2016)

Specific Power or Specific Resistance

$$\varepsilon = \frac{P}{W \cdot V}$$

ε: Specific Power
P: Max. Power
W: Vehicle Weight
V: Max. Velocity

A= 0,000175 h/mile

RESTRICTIONS

But some things are not taken into consideration, such as:

- Power used at cruising speed
- Market weight to total weight ratio
- Lack of analysis of the energy to transport the payload
- No clear indication of the consumption per transported person
- Whether it is primary or final energy, information is required

The Improved Karman-Gabrielli Diagram

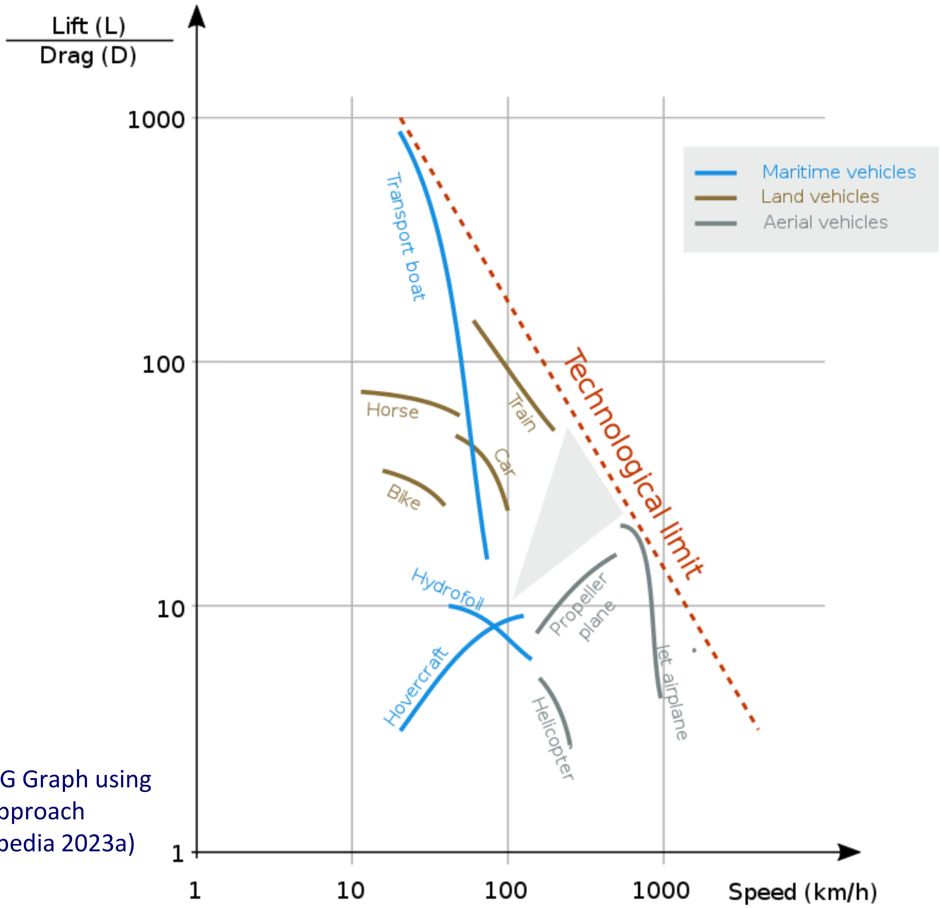
The Inverse of Specific Resistance

$$\frac{1}{\varepsilon} = \frac{W \cdot V}{P} = \frac{W}{D} = \frac{L}{D}$$

In Naval Architecture

$$\frac{1}{\varepsilon} = \frac{\Delta}{R_V}$$

Δ : Loaded displacement
R_V : Ship's drag



The KG Graph using L/D approach (Wikipedia 2023a)

Equations for the Modes of Transportation

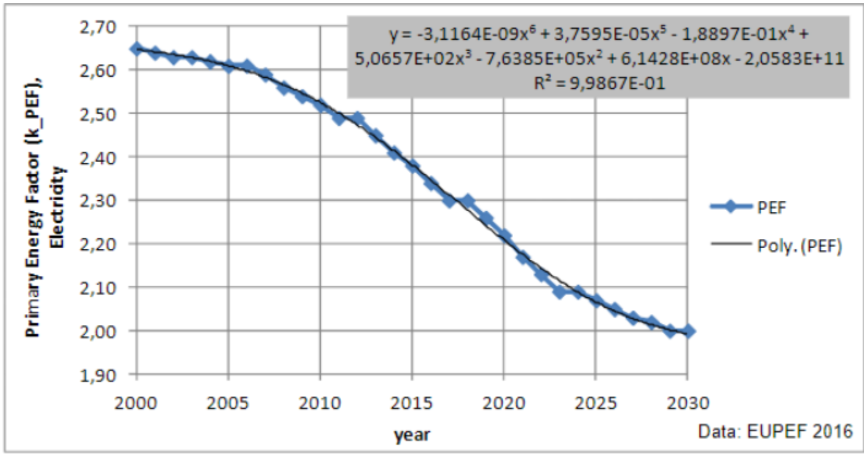
Parameters

- Lift over drag: $\frac{L}{D}$
- Payload Fraction times lift over drag: $\left(\frac{L}{D}\right)_{pl}$

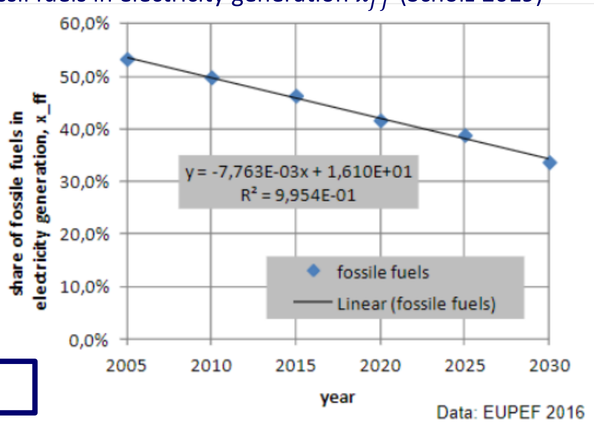
$$\left(\frac{L}{D}\right)_{pl} = \frac{m_{pl}}{m} \cdot \left(\frac{L}{D}\right)$$

- Energy consumption per payload and range: $\frac{E}{s \cdot m_{pl}}$
- Primary energy consumption per payload and range: $\frac{E_{prim}}{s \cdot m_{pl}}$
  - Diesel or gas operated: $\frac{E_{prim}}{s \cdot m_{pl}} = 1{,}1 \cdot \frac{E}{s \cdot m_{pl}}$
  - Electrically powered: $\frac{E_{prim}}{s \cdot m_{pl}} = k_{PEF} \cdot \frac{E}{s \cdot m_{pl}}$
- CO2 mass to payload mass and range: $\frac{m_{CO2}}{s \cdot m_{pl}}$
  - Diesel or gas operated: $m_{CO2} = 3{,}15 \cdot 1{,}1 \cdot m_f$
  - Electrically powered: $m_{CO2} = 3{,}15 \cdot x_{ff} \cdot E_{prim}/H_L$
- Equivalent CO2 mass to payload mass and range: $\frac{m_{eq,CO2}}{s \cdot m_{pl}}$
  - Diesel or gas operated: $m_{CO2,eq} = m_{CO2}(k_{RFI} + 0{,}1)$
  - Electrically powered: $m_{CO2,eq} = m_{CO2}$

Primary energy factor k_{PEF} (Scholz 2019)



Share of fossil fuels in electricity generation x_{ff} (Scholz 2019)



k_{RFI} (Radiative Forcing Index) = 2,7

Equations for the Modes of Transportation

L/D=…

Air Transport	Water Transport	Land Transport	Pipeline Transport
Subsonic Fixed-Wing Aircraft $k_E \sqrt{\frac{A}{\frac{S_{wet}}{S_W}}}$	Bulker, Tanker and Container Vessel $\frac{\Delta \cdot g}{R_T}$	Car, Truck and Bus $\frac{m \cdot g}{R_T} = \frac{m \cdot g}{R_A + R_R}$	Hyperloop $\frac{m \cdot g}{R_A + R_B}$
Supersonic Fixed-Wing Aircraft $\frac{3(M+3)}{M}$	Cruise Ship $\frac{\Delta \cdot g}{R_F}$	High Speed Train $\frac{m \cdot g}{R_T}$	Oil and Gas Pipeline $\frac{2 \cdot d \cdot g}{\lambda \cdot V^2}$
Rotorcraft $\frac{m \cdot V}{P_{cont}}$ $or \approx 4$		Human and Animal $\frac{m \cdot V}{P}$	
Airship $\frac{m \cdot g}{D_0}$			
Glider $\frac{horizontal\ distance}{elevation\ change}$			

Equations for the Modes of Transportation

E/s*m_pl=…

Air Transport	Water Transport	Land Transport	Pipeline Transport
Subsonic Fixed-Wing Aircraft $\frac{1}{SAR} \cdot \frac{H_L}{m_{pl}} = \frac{m_F \cdot H_L}{s \cdot m_{pl}}$	Bulker, Tanker and Container Vessel $\frac{E}{t} \cdot \frac{1}{V \cdot m_{pl}}$	Car, Truck and Bus $\frac{m_f \cdot H_L}{s \cdot m_{pl}}$	Hyperloop $4{,}4 \frac{kWh}{100km \cdot person}$
Supersonic Fixed-Wing Aircraft $\frac{1}{SAR} \cdot \frac{H_L}{m_{pl}} = \frac{m_F \cdot H_L}{s \cdot m_{pl}}$	Cruise Ship $\frac{m_f \cdot H_L}{s \cdot m_{pl}}$	High Speed Train $60 \frac{Wh}{pax \cdot km}$	Oil and Gas Pipeline Diesel/gas $\frac{1}{2} \cdot V^2 \cdot \frac{\lambda}{d} \cdot \frac{1}{0{,}75 \cdot 0{,}3 \cdot 0{,}9}$ Electric $\frac{1}{2} \cdot V^2 \cdot \frac{\lambda}{d} \cdot \frac{1}{0{,}75 \cdot 0{,}9}$
Rotorcraft $\frac{H_L \cdot m_f}{R \cdot m_{pl}}$		Human and Animal $\frac{E}{s \cdot m_{pl}}$	
Airship $\frac{H_L \cdot \frac{m_f}{t}}{V \cdot m_{pl}}$			
Glider -			

Equations for the Modes of Transportation

Air Transport – Subsonic Fixed-Wing Aircraft

Maximum lift over drag

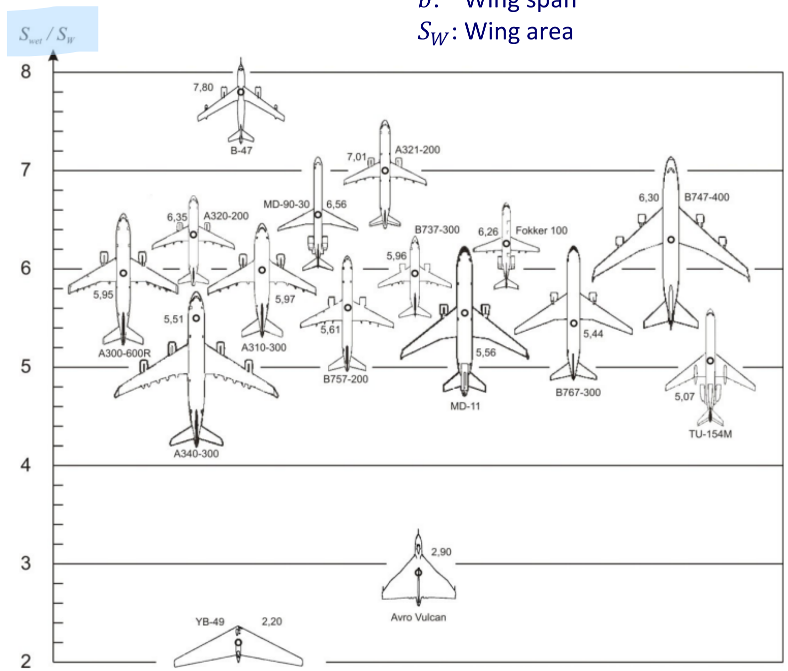
$$\left(\frac{L}{D}\right)_{max} = k_E \sqrt{\frac{A}{S_{wet}/S_W}}$$

$$A = \frac{b^2}{S_W}$$

Flight length	kE
Short Range	15,15
Medium Range	16,19
Long Range	17,25

(Scholz 2022)

A: Aspect ratio
b: Wing span
S_W: Wing area



Wetted Surface and Wing Surface Ratio of Aircraft (Scholz 2022)

Energy consumption per payload range

$$\frac{E}{s \cdot m_{pl}} = \frac{1}{SAR} \cdot \frac{H_L}{m_{pl}} = \frac{m_f \cdot H_L}{s \cdot m_{pl}}$$

$$SAR = \frac{VE}{cg} \cdot \frac{1}{m} = \frac{s}{m_f}$$

$$c = 3{,}735 \cdot 10^{-8} \cdot \lambda^{-2{,}12 \cdot 10^{-3}} \cdot V + 1{,}65 \cdot 10^{-5} \cdot \lambda^{-0{,}4}$$

SAR: Specific Air Range
H_L: Heating value
c : Thrust specific fuel consumption (SFC)
λ: Bypass ratio

Primary energy consumption per payload range

$$\frac{E_{prim}}{s \cdot m_{pl}} = 1{,}1 \cdot \frac{E}{s \cdot m_{pl}}$$

Equations for the Modes of Transportation

Air Transport – Supersonic Fixed-Wing Aircraft

Maximum lift over drag

$$\left(\frac{L}{D}\right)_{max} = \frac{3(M+3)}{M}$$

$$M = \frac{V}{a}$$

M: Mach number

Energy consumption per payload range

$$\frac{E}{s \cdot m_{pl}} = \frac{1}{SAR} \cdot \frac{H_L}{m_{pl}} = \frac{m_f \cdot H_L}{s \cdot m_{pl}}$$

$$SAR = \frac{V \cdot \frac{L}{D}}{cg} \cdot \frac{1}{m} = \frac{s}{m_f}$$

SAR: Specific Air Range
H_L: Heating value
c : Thrust specific fuel consumption (SFC)
λ: Bypass ratio

$$c = 3{,}735 \cdot 10^{-8} \cdot \lambda^{-2{,}12 \cdot 10^{-3}} \cdot V + 1{,}65 \cdot 10^{-5} \cdot \lambda^{-0{,}4}$$

Primary energy consumption per payload range

$$\frac{E_{prim}}{s \cdot m_{pl}} = 1{,}1 \cdot \frac{E}{s \cdot m_{pl}}$$

Air Transport – Rotorcraft

P_{cont}: Continuous power
R: Cruise range

Lift over drag

$$\frac{L}{D} = \frac{m \cdot V}{P_{cont}}$$ =3....4

Energy consumption per payload range

$$\frac{E}{s \cdot m_{pl}} = \frac{H_L \cdot m_f}{R \cdot m_{pl}}$$

Primary energy consumption per payload range

$$\frac{E_{prim}}{s \cdot m_{pl}} = 1{,}1 \cdot \frac{E}{s \cdot m_{pl}}$$

Equations for the Modes of Transportation

Air Transport – Airship

Lift over drag

$$\left(\frac{L}{D}\right) = \frac{m \cdot g}{D_0}$$

$$D_0 = \frac{1}{2} \cdot \rho_{air} \cdot V^2 \cdot c_{DV} \cdot S_V$$

$$C_{DV} = \left[0{,}172 \left(\frac{l}{d}\right)^{\frac{1}{3}} + 0{,}252 \left(\frac{d}{l}\right)^{0{,}2} + 1{,}032 \left(\frac{d}{l}\right)^{2{,}7}\right] \cdot \frac{1}{Re^{\frac{1}{6}}}$$

$$S_V = Vol^{\frac{2}{3}}$$

$$Re = \frac{V \cdot l}{\nu}$$

D_0: Zero-lift drag
ρ_{air}: Air density
c_{DV}: Coefficient of drag
V: Cruise speed
S_V: Reference area calculated from the volume of airship
l: Length of the airship
d: Diameter of the airship
Vol: Volume of the airship envelopes
V: Cruise speed
l: Length of the airship
ν: Kinematic viscosity

Energy consumption per payload range

$$\frac{E}{s \cdot m_{pl}} = \frac{H_L \cdot \frac{m_f}{t}}{V \cdot m_{pl}}$$

Primary energy consumption per payload range

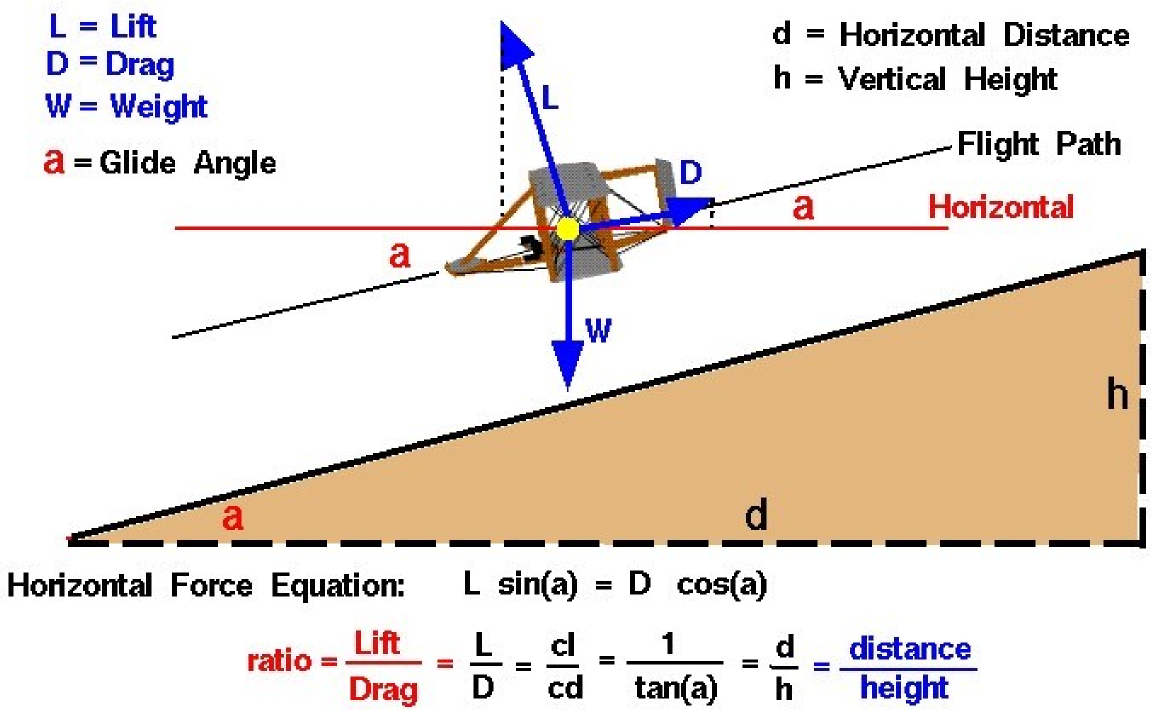
$$\frac{E_{prim}}{s \cdot m_{pl}} = 1{,}1 \cdot \frac{E}{s \cdot m_{pl}}$$

H_L : Heating value
m_f/t: Fuel consumption per time

Air Transport – Glider

Lift over drag

$$\frac{L}{D} = \frac{distance}{height}$$

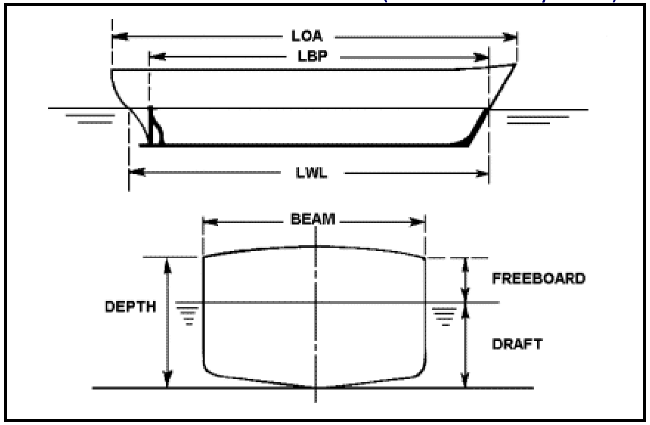


Lift to Drag Ratio of Glider (NASA 2023)

Equations for the Modes of Transportation

Water Transport – Bulker, Tanker and Container Vessel

(Global Security 2011)



Lift over drag

$$\frac{L}{D} = \frac{\Delta \cdot g}{R_T}$$

$$R_T = \frac{1}{2} \cdot C_T \cdot \rho \cdot S_W \cdot V^2$$

$$C_T = C_F + C_A + C_{AA} + C_R$$

Hans Otto Kristensen

Vessel Type	$C_{AA} \cdot 1000$
Small tankers	0,07
Handysize tankers	0,07
Handymax tankers	0,07
Panamax tankers	0,05
Aframax tankers	0,05
Suezmax tankers	0,05
VLCC	0,04

$$C_F = \frac{0{,}075}{(log Re - 2)^2}$$

$$Re = \frac{V \cdot L_{wl}}{\nu}$$

$$1000 \cdot C_A = 0{,}5 \cdot \log(\Delta) - 0{,}1 \cdot (\log(\Delta))^2$$

$$S_W = 1{,}025 \cdot \left(\frac{\nabla}{T} + 1{,}7 \cdot L_{pp} \cdot T\right)$$

Energy consumption per payload range

$$\frac{E}{s \cdot m_{pl}} = \frac{E}{t} \cdot \frac{1}{V \cdot m_{pl}}$$

Primary energy consumption per payload range

$$\frac{E_{prim}}{s \cdot m_{pl}} = 1{,}1 \cdot \frac{E}{s \cdot m_{pl}}$$

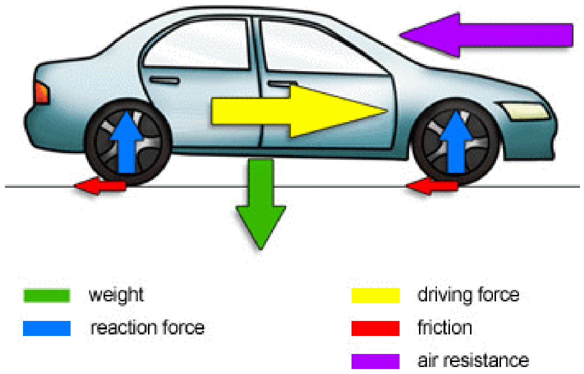
$$\frac{E}{t} = \frac{m_{oil,auxilary\ engine}}{t} \cdot H_L + \frac{m_{oil,main\ engine}}{t} \cdot H_L$$

R_T: Total resistance
C_T: Total resistance coefficient
C_F: Frictional resistance coefficient
C_A: Incremental coefficient
C_{AA}: Air resistance coefficient
C_R: Residual coefficient
Δ: Loaded displacement
L_{wl}: Length of waterline
ν: Kinematic viscosity $\approx 1{,}14 \cdot 10^{-6} \frac{m^2}{s}$ at 15°C
S_W: Wetted area
∇: Volume displacement
T: Draught
L_{pp}: Length between perpendicular

Equations for the Modes of Transportation

(Somers 2017)

Land Transport – Car, Truck and Bus



Lift over drag

$$\frac{L}{D} = \frac{m \cdot g}{R_T}$$

$$R_T = R_A + R_R$$

$$R_R = m \cdot g \cdot \mu_R$$

$$R_A = \frac{1}{2} \cdot \rho_{air} \cdot c_d \cdot A_f \cdot V^2$$

Track	μ_R
Car tires and asphalt	0,015
Car tires and earth way	0,05

Rolling Friction Coefficient (Scholz 2022)

R_T: Total resistance
R_A: Aerodynamic resistance
R_R: Rolling resistance
c_d: Drag coefficient
A_f: Frontal area
μ_R: Rolling friction coefficient

Energy consumption per payload range

$$\frac{E}{s \cdot m_{pl}} = \frac{m_f \cdot H_L}{s \cdot m_{pl}}$$

Primary energy consumption per payload range

Diesel or gas

$$\frac{E_{prim}}{s \cdot m_{pl}} = 1{,}1 \cdot \frac{E}{s \cdot m_{pl}}$$

Electric

$$\frac{E_{prim}}{s \cdot m_{pl}} = k_{PEF} \cdot \frac{E}{s \cdot m_{pl}} = 2{,}1 \cdot \frac{E}{s \cdot m_{pl}}$$

Equations for the Modes of Transportation

Land Transport – High Speed Train

Lift over drag

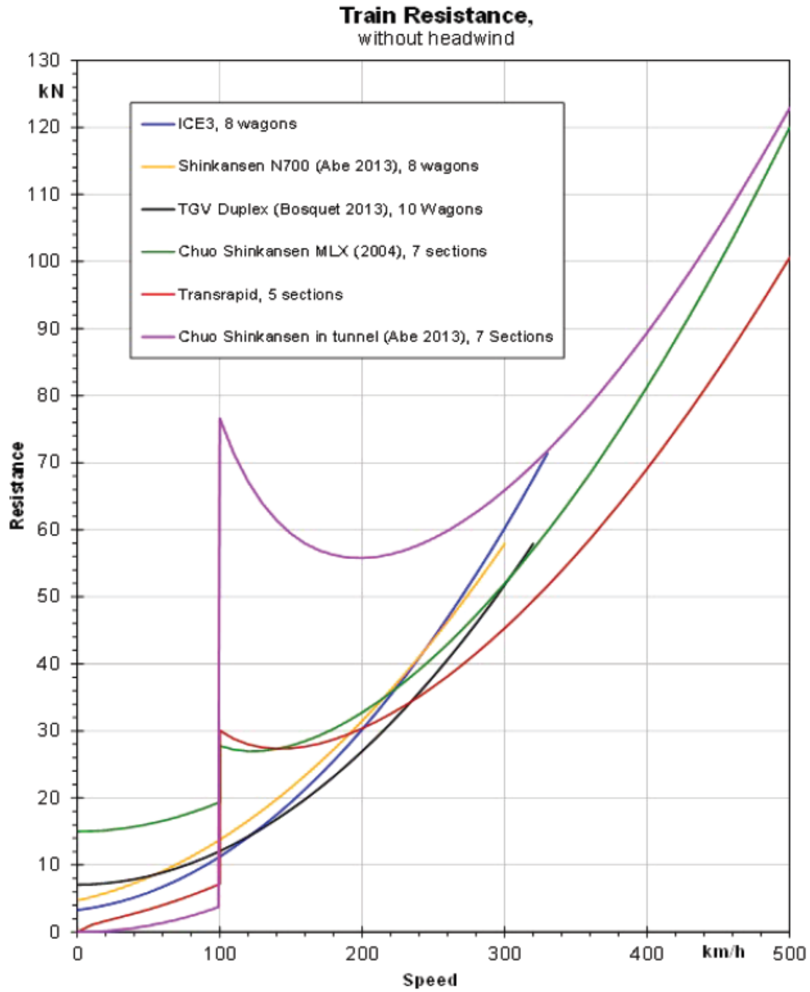
$$\frac{L}{D} = \frac{m \cdot g}{R_T}$$

Types of train resistance:
- Rolling resistance
- Wind resistance
- Acceleration resistance
- Starting resistance
- Curve and grade resistance

Energy consumption per distance and payload (Scholz…):
60 Wh/pax km

Primary energy consumption per payload range

$$\frac{E_{prim}}{s \cdot m_{pl}} = k_{PEF} \cdot \frac{E}{s \cdot m_{pl}} = 2{,}1 \cdot \frac{E}{s \cdot m_{pl}}$$



Resistances of high speed train (Fritz 2018)

Land Transport – Human and Animal

Lift over drag

$$\frac{L}{D} = \frac{m \cdot V}{P}$$

Primary energy consumption per payload range

$$\frac{E_{prim}}{s \cdot m_{pl}} = \frac{E}{s \cdot m_{pl}}$$

TABLE 2 DATA ON LIVING POWER PLANTS

Kind of locomotion	Weight, lb	Speed, mph	Power, hp
Man—Walking and Running			
Walking	155	3	0.084
Marching fast	135	9	0.30
100-yard runner	122	22.4	0.90
Man—On Bicycle			
Pleasure trip	185	15.5	0.25
Speeding on highway	160	25.0	0.47
On racetrack	155	38.1	1.01
Horse			
With carriage, at fast step	3500	4.5	0.64
With carriage, trotting	2650	9.0	0.85
Racehorse in gallop, with jockey	1000	38.5	2.0

(Gabrielli 1950)

(Wikipedia 2023b) (Ebert 2020)

	E/m [MJ/kg]	E/(s*m) [J/mpax]
Human walking, human marching fast and 100 yard runner		200
Bicycle pleasure trip, bicycle speeding on highway, bicycle on racetrack		110
Horse with carriage with fast step, horse with carriage by trotting, racehorse	0,02	

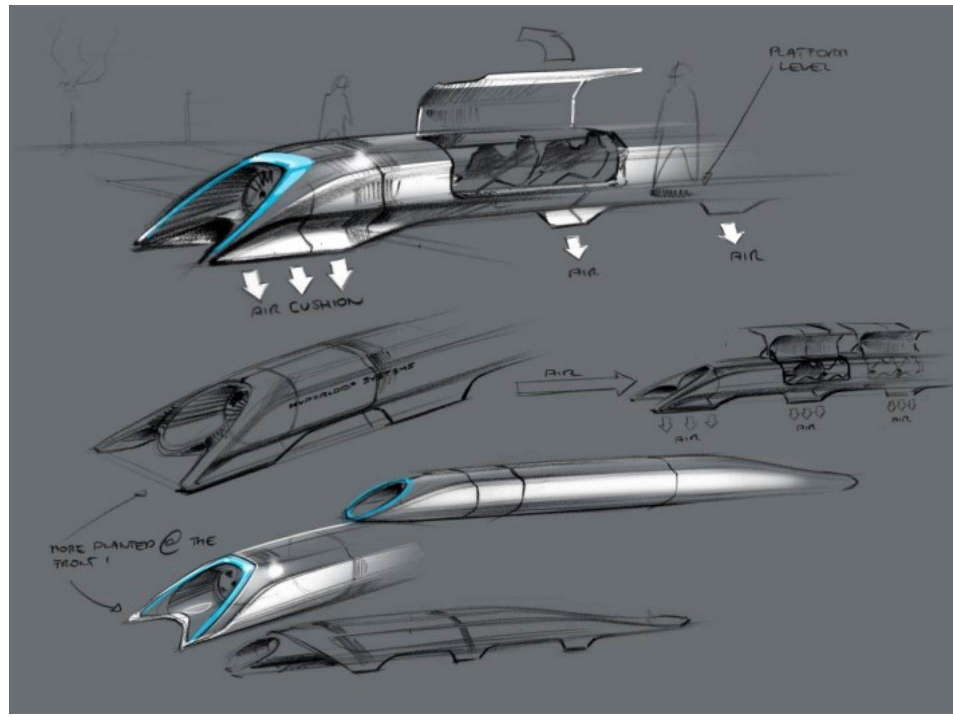
Pipeline Transport - Hyperloop

Lift over drag

$$\frac{L}{D} = \frac{m \cdot g}{R_A + R_B}$$

R_A: Aerodynamic drag
R_B: Air bearings drag

Energy consumption per distance and payload:
4,4 kWh/1oo km per person



Hyperloop passenger transport capsule conceptual design sketch (Musk 2013)

HAW HAMBURG

Equations for the Modes of Transportation

Δp : Pressure differential
λ : Pipe friction coefficient
d : Diameter of the pipe
l: Length of the pipe
A: Cross-sectional vector area
$\dot{V}$: Volumetric flow rate
Re: Reynoldsnumber

Pipeline Transport – Oil and Gas Pipeline

Lift over drag

$$\frac{L}{D} = \frac{m \cdot g}{\Delta p \cdot A} = \frac{2 \cdot d \cdot g}{\lambda \cdot V^2}$$

$$\Delta p = \frac{1}{2} \rho V^2 \lambda \frac{l}{d} \quad \text{...(c)}$$

$$\lambda = \frac{0{,}3164}{\sqrt[4]{Re}}$$

$$Re = \frac{V \cdot d}{\nu}$$

$$\frac{L}{D} = \frac{m \cdot g}{\Delta p \cdot A} \overset{(b)}{\underset{(c)}{=}} \frac{\rho \cdot A \cdot l \cdot g}{\frac{1}{2} \cdot \rho \cdot V^2 \cdot \lambda \cdot \frac{l}{d} \cdot A} = \frac{2 \cdot d \cdot g}{V^2 \cdot \lambda}$$

Power $P = \Delta p \cdot \dot{V} = \Delta p \cdot A \cdot V \quad \text{...(a)}$

Energy $E = P \cdot t = \Delta p \cdot A \cdot V \cdot t = \Delta p \cdot A \cdot l$

$$\frac{E}{l} = \Delta p \cdot A \overset{(a)}{=} \frac{P}{V}$$

$$\dot{m} = \rho \cdot \dot{V} = \rho \cdot A \cdot V$$

$$m = \dot{m} \cdot t = \rho \cdot \dot{V} \cdot t \overset{(a)}{=} \rho \cdot A \cdot V \cdot t = \rho \cdot A \cdot l \quad \text{...(b)}$$

$$\frac{E}{l \cdot m} = \frac{\Delta p \cdot A \cdot l}{l \cdot m} = \frac{\Delta p \cdot A}{m} \overset{(b)}{=} \frac{\Delta p \cdot A}{\rho \cdot A \cdot l} = \frac{\Delta p}{\rho \cdot l} \overset{(c)}{=} \frac{\frac{1}{2} \cdot \rho V^2 \lambda \frac{l}{d}}{\rho \cdot l} = \frac{1}{2} \cdot V^2 \cdot \frac{\lambda}{d}$$

Primary energy consumption per payload range

$$\frac{E}{s \cdot m_{pl}} = \frac{1}{2} \cdot V^2 \cdot \frac{\lambda}{d}$$

Primary energy consumption per payload range

Diesel or gas

$$\frac{E_{prim}}{s \cdot m_{pl}} = \frac{E}{s \cdot m_{pl}} \cdot \frac{1}{0{,}75 \cdot 0{,}3 \cdot 0{,}9}$$

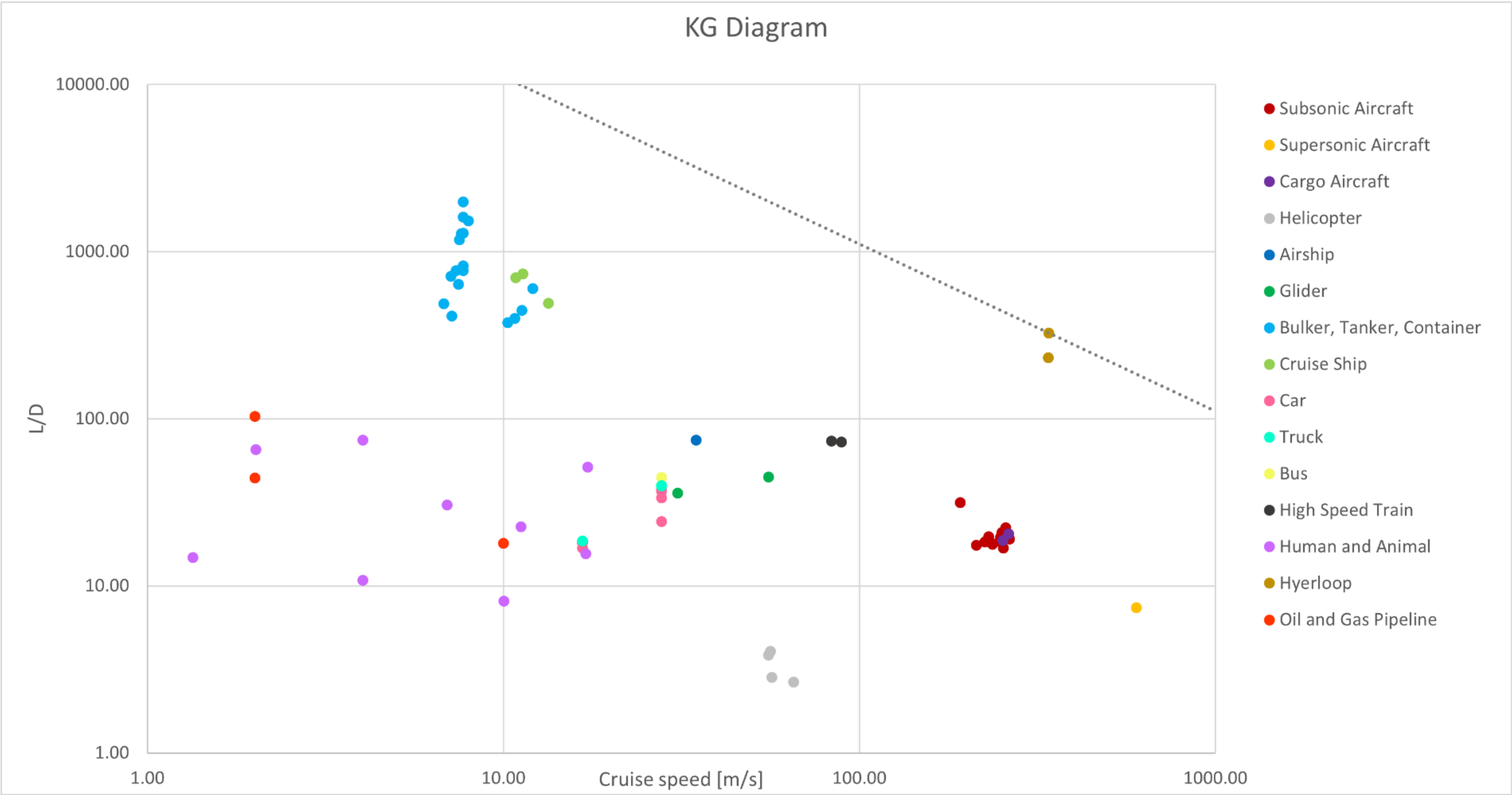
Electric

$$\frac{E_{prim}}{s \cdot m_{pl}} = \frac{E}{s \cdot m_{pl}} \cdot \frac{1}{0{,}75 \cdot 0{,}9}$$

Results of New KG-Diagram

Results of New KG-Diagram

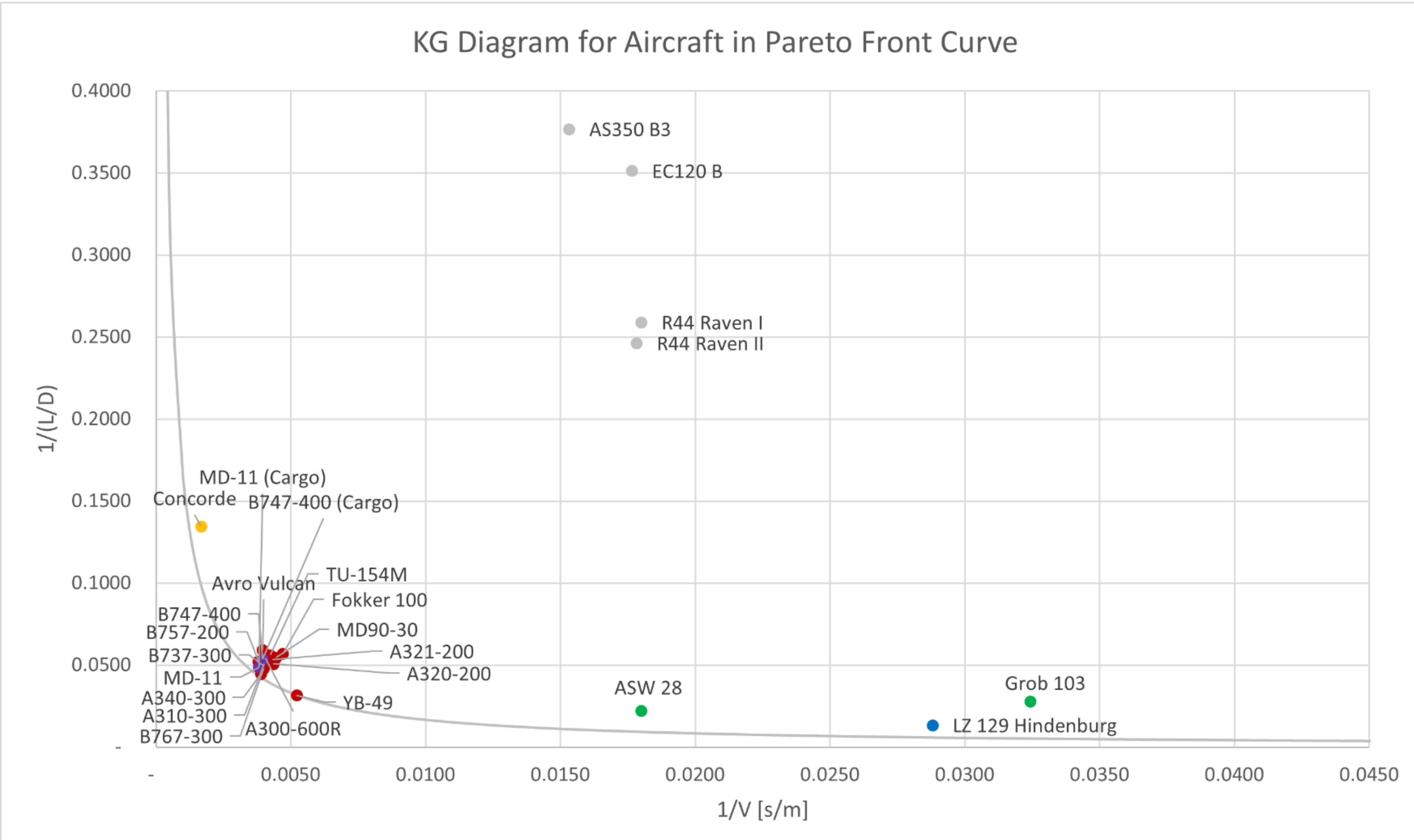
KG Diagram: Lift over Drag



Karman-Gabrielli diagram for all vehicles

Results of New KG-Diagram

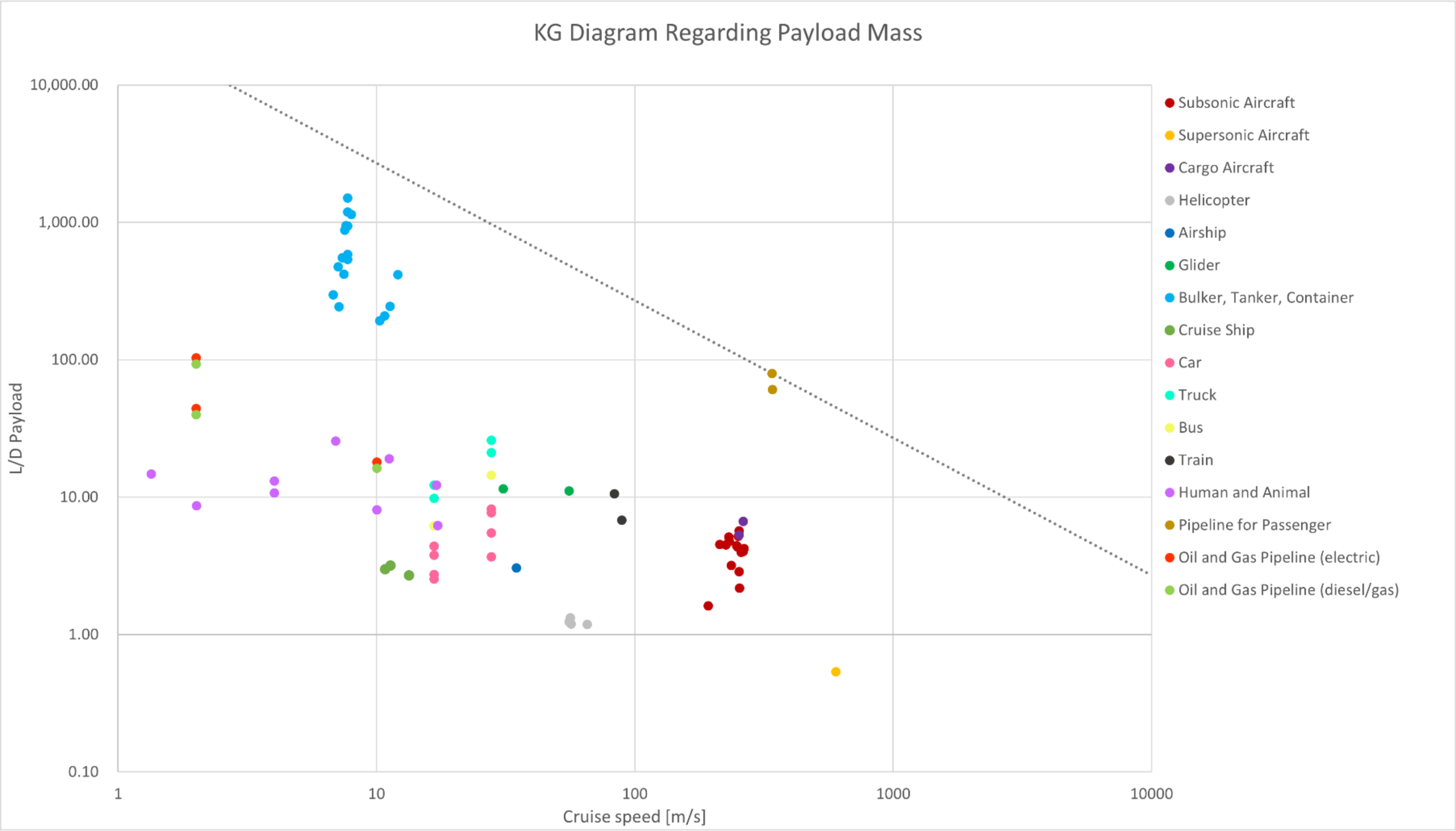
KG Diagram: Lift over Drag in Pareto Front Curve



Karman-Gabrielli diagram for all vehicles in Pareto front curve

Results of New KG-Diagram

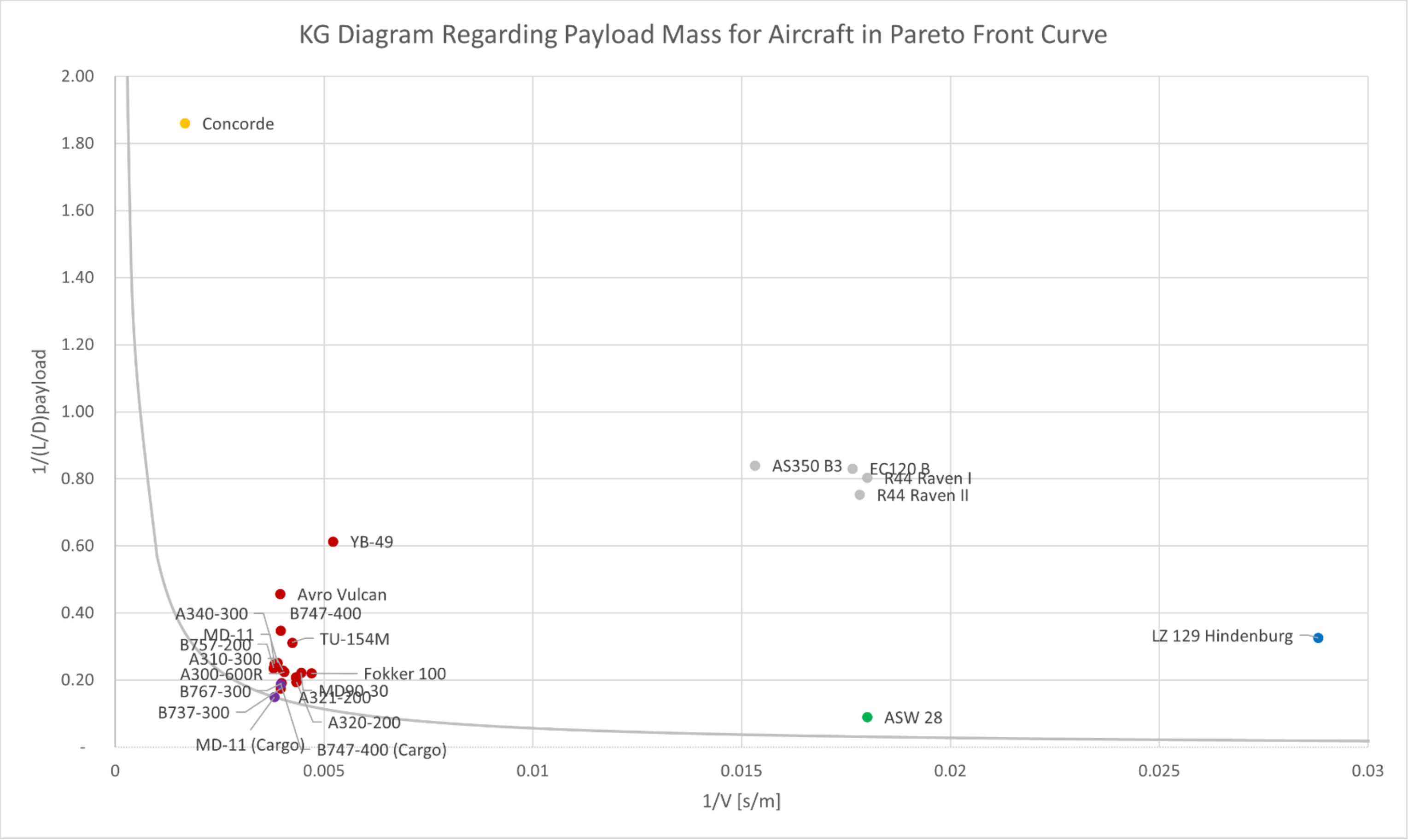
KG Diagram: Payload Fraction times Lift over Drag



Karman-Gabrielli diagram regarding payload mass for all vehicles

Results of New KG-Diagram

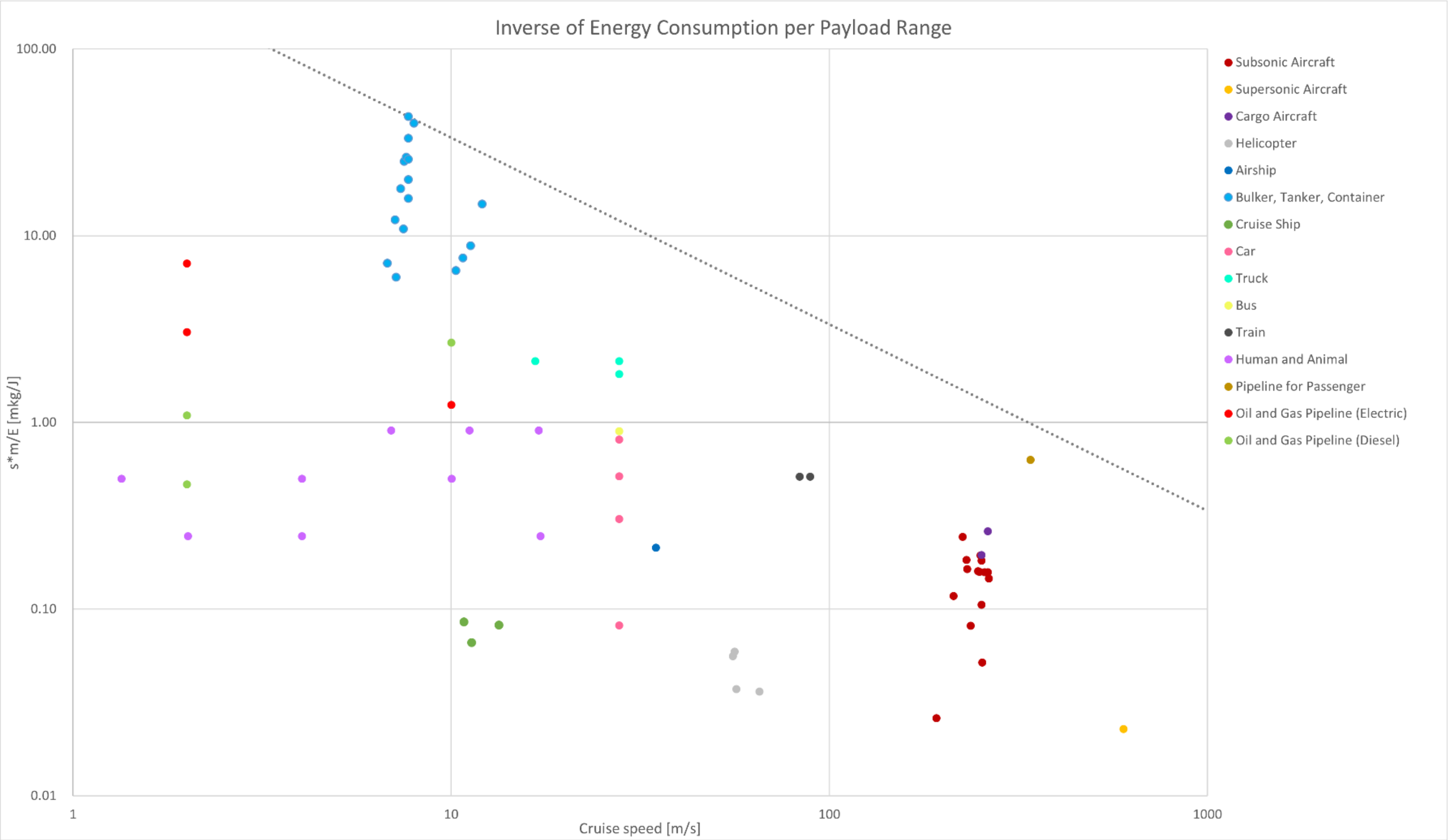
KG Diagram: Payload Fraction times Lift over Drag



Karman-Gabrielli diagram regarding payload mass for all vehicles in Pareto front curve

Results of New KG-Diagram

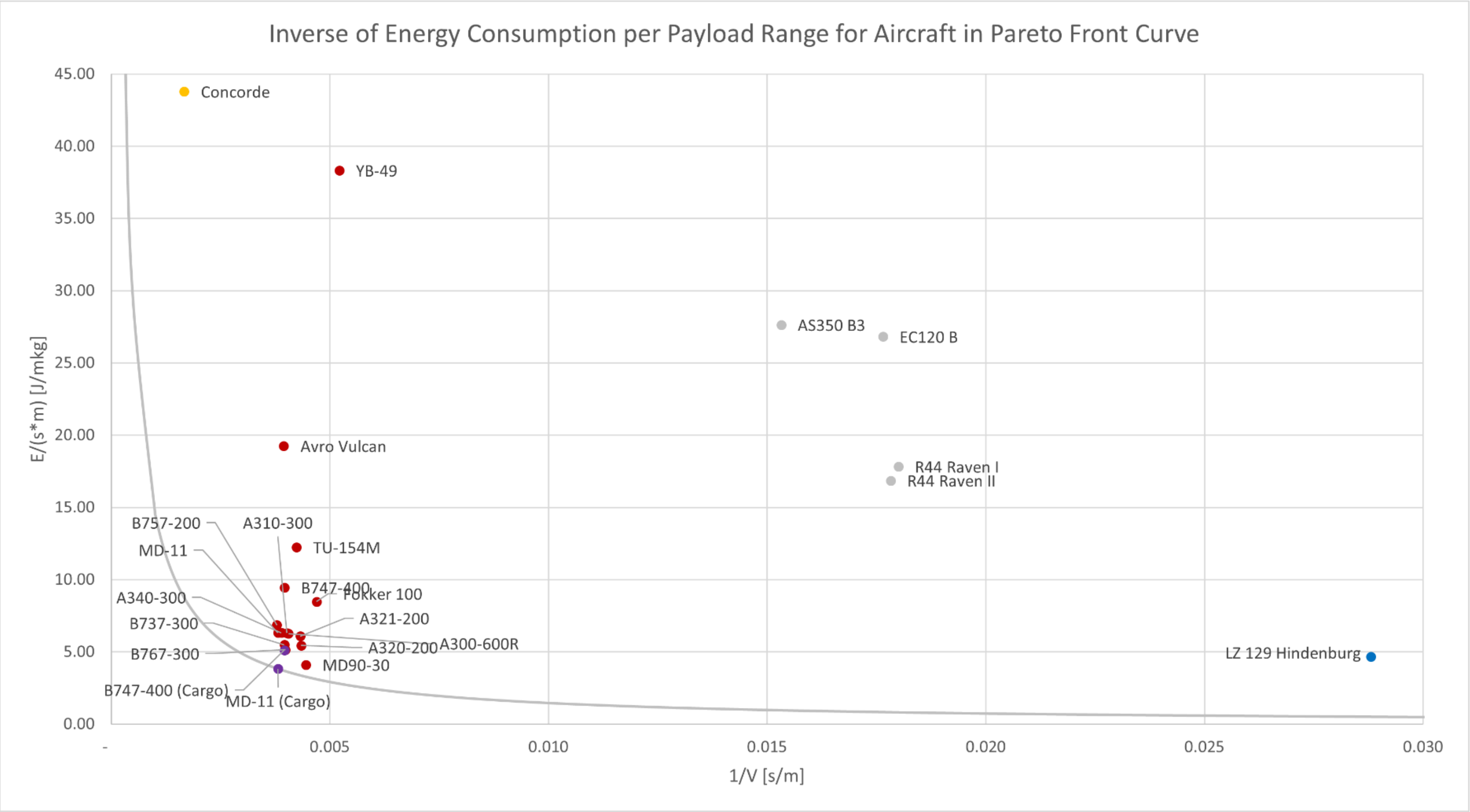
KG Diagram: Inverse of Energy Consumption per Payload and Range



Inverse of energy consumption per payload and range for all vehicles

Results of New KG-Diagram

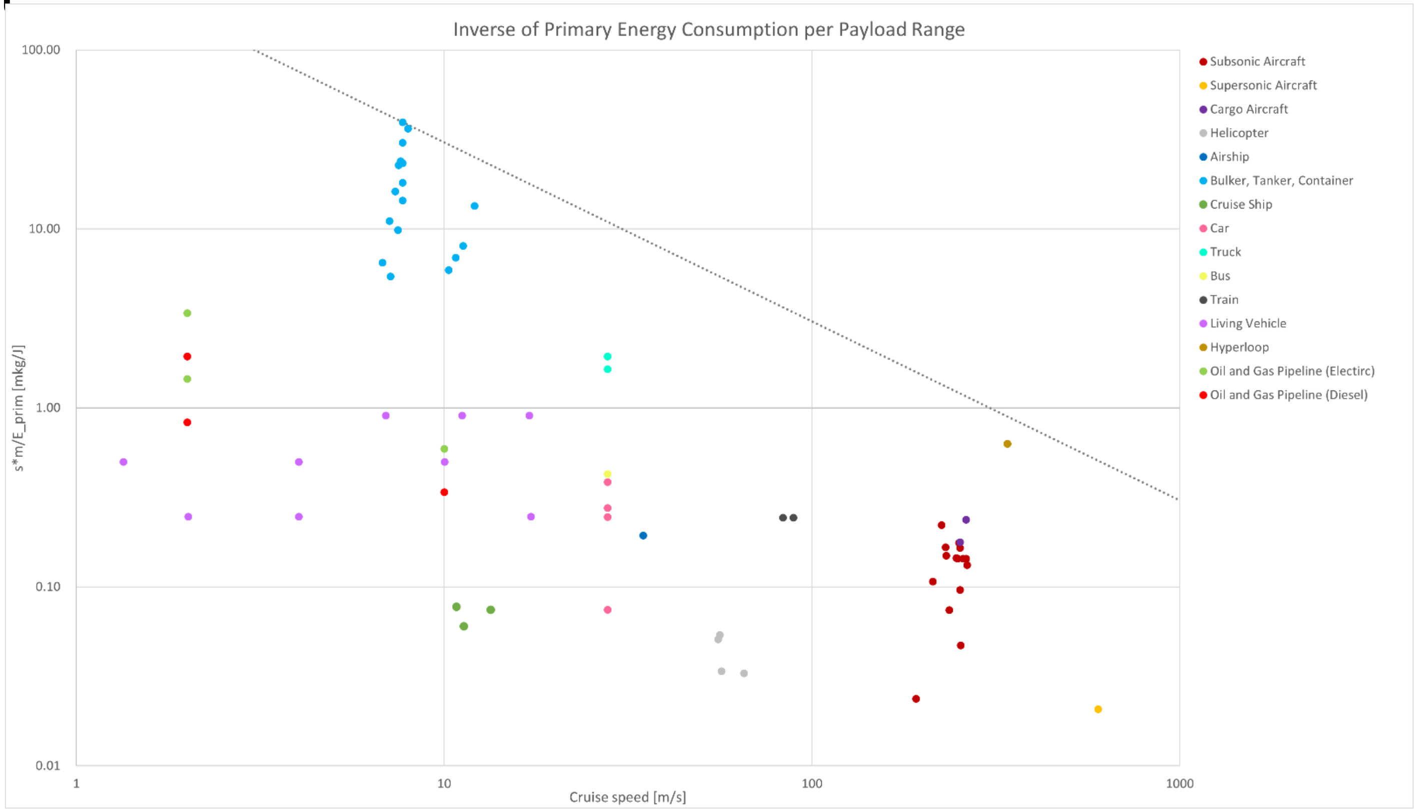
KG Diagram: Inverse of Energy Consumption per Payload Range for Aircraft in Pareto Front Curve



Inverse of energy consumption per payload and range for all vehicles in Pareto front

Results of New KG-Diagram

KG Diagram: Inverse of Primary Energy Consumption per Payload Range for Aircraft



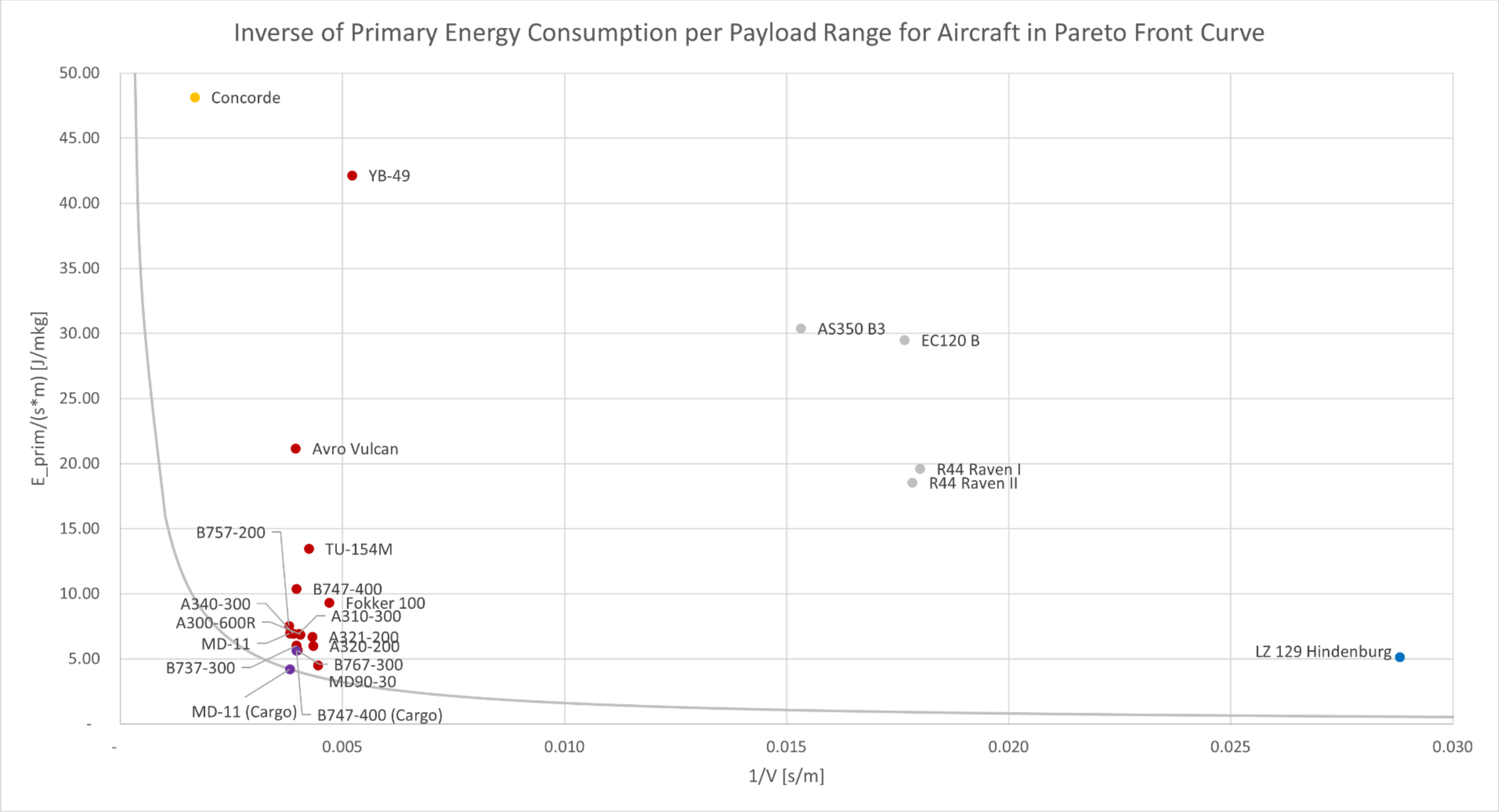
Inverse of primary energy consumption per payload and range for all vehicles

Primary energy consumption per payload and range: $\frac{E_{prim}}{s \cdot m_{pl}}$

Diesel or gas operated: $\frac{E_{prim}}{s \cdot m_{pl}} = 1{,}1 \cdot \frac{E}{s \cdot m_{pl}}$

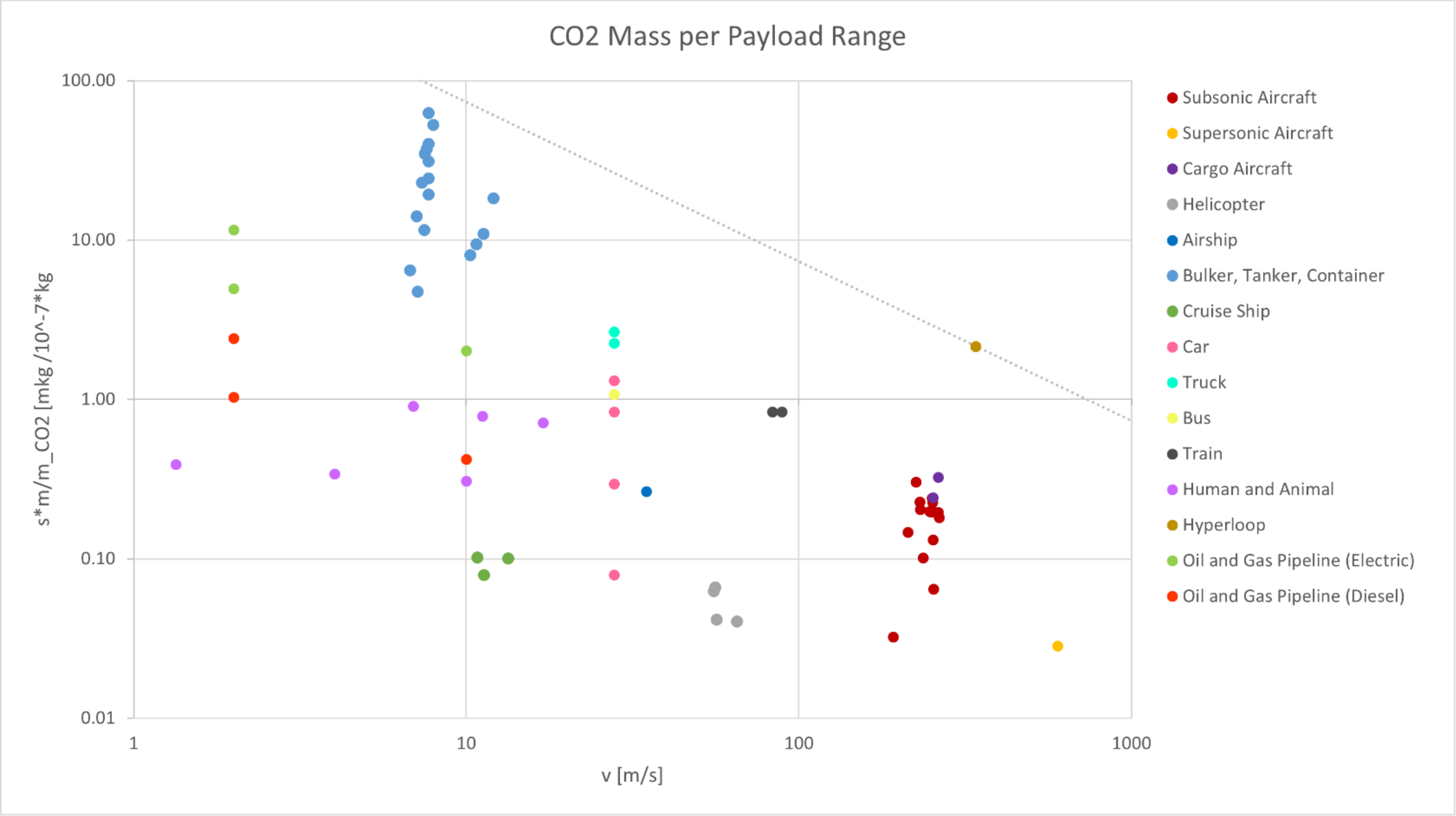
Electrically powered: $\frac{E_{prim}}{s \cdot m_{pl}} = k_{PEF} \cdot \frac{E}{s \cdot m_{pl}}$

KG Diagram: Inverse of Primary Energy Consumption per Payload Range for Aircraft in Pareto Front Curve



Inverse of primary energy consumption per payload and range for all vehicles in Pareto front

Results of New KG-Diagram
KG Diagram: Inverse of CO2 Mass to Payload and Range



CO2 mass to payload mass: $\frac{m_{CO2}}{s \cdot m_{pl}}$

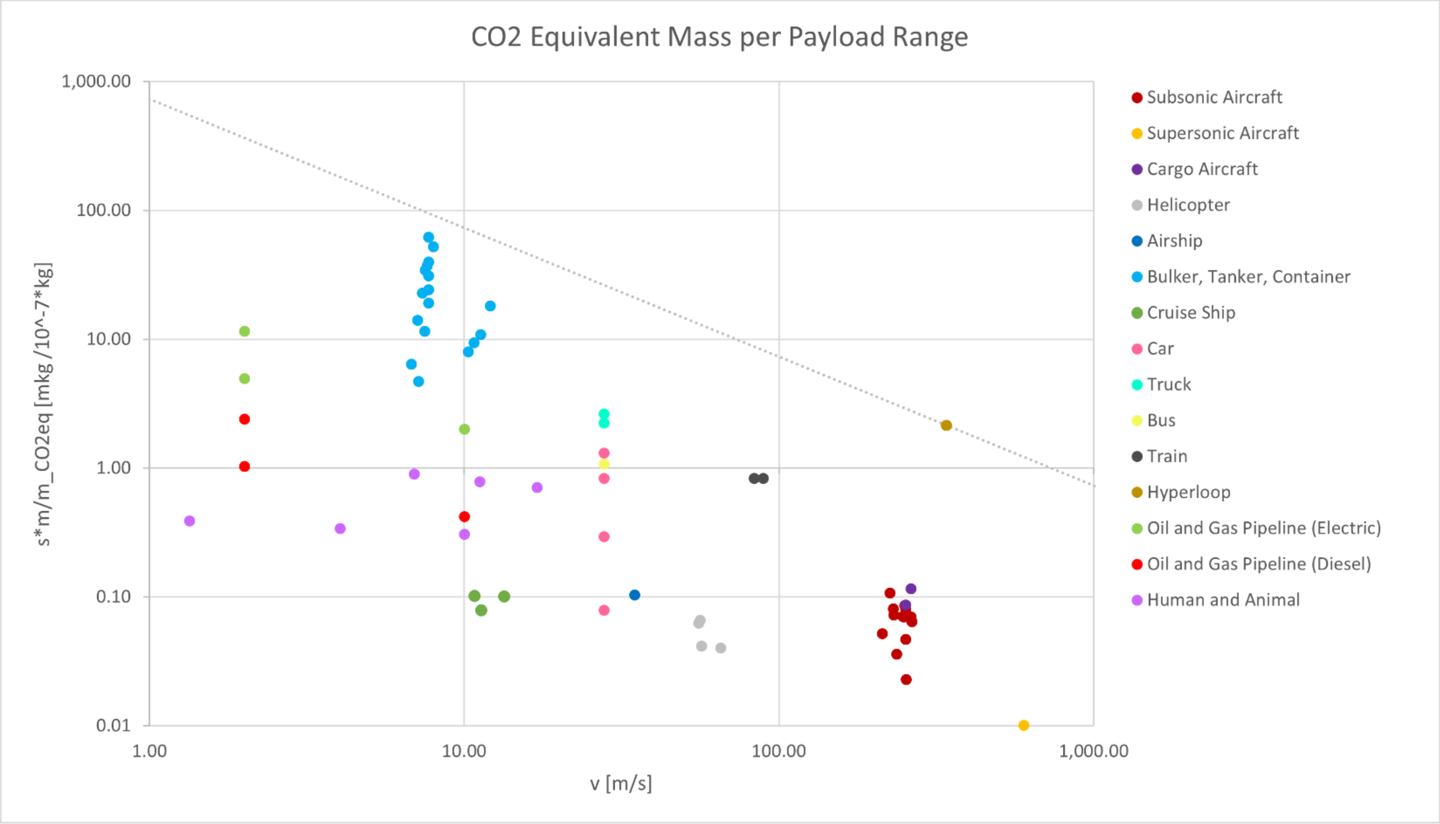
Diesel or gas operated: $m_{CO2} = 3{,}15 \cdot 1{,}1 \cdot m_f$

Electrically powered: $m_{CO2} = 3{,}15 \cdot x_{ff} \cdot E_{prim}/H_L$

Inverse of CO2 mass per payload and range for all vehicles

Results of New KG-Diagram

KG Diagram: Inverse of Equivalent CO2 Mass to Payload and Range



Inverse of equivalent CO2 mass per payload and range for all vehicles

Equivalent CO2 mass to payload mass: $\frac{m_{eq,CO2}}{s \cdot m_{pl}}$

Diesel or gas operated: $m_{CO2,eq} = m_{CO2}(k_{RFI} + 0{,}1)$

Electrically powered: $m_{CO2,eq} = m_{CO2}$

Summary

Summary

- It is a philosophical decision, whether people would maximize speed or maximize carrying capacity.
- Regardless of the vehicle's low transport figure of merit, they also have some reasons to be still available in operation.
- The medium where they travel is also one of the important aspects. Water has a higher density than air, which causes a ship to exhibit greater lift than an airship.
- Public transportation is typically more effective for transporting individuals due to ist greater capability to transport passenger, reduced energy consumption and lower per-passenger carbon dioxide equivalent emissions than private vehicles.
- Public transportation which electrically powered must be more developed in the future.
- As technology progresses, the technological limit line in KG-Diagram will undergo continuous modification.
- Non essential trips should be avoided.

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