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Comparing Modes of Transportation with an Improved Karman-Gabrielli Diagram

Karman & Gabrielli asked 1950: „What price speed?“ – Today we ask: „How much climate burden for speed?“

We have heard: "Time is Money". We do not agree on a specific "Value of Time". However, we do agree that the "Value of Time" is proportional to time. Speed reduces time. "Money" can also be Drag, Energy, CO2, or Equivalent CO2. We may agree to spend twice the energy (money), if we can double the speed. Unfortunately, aerodynamic drag is proportional to speed square. Hence, the laws of physics favor slow speed in this trade-off. Can any mode of transportation beat the laws of physics to enable high speed transport? Or will we be bound to go slow in the future?

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 front.

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.

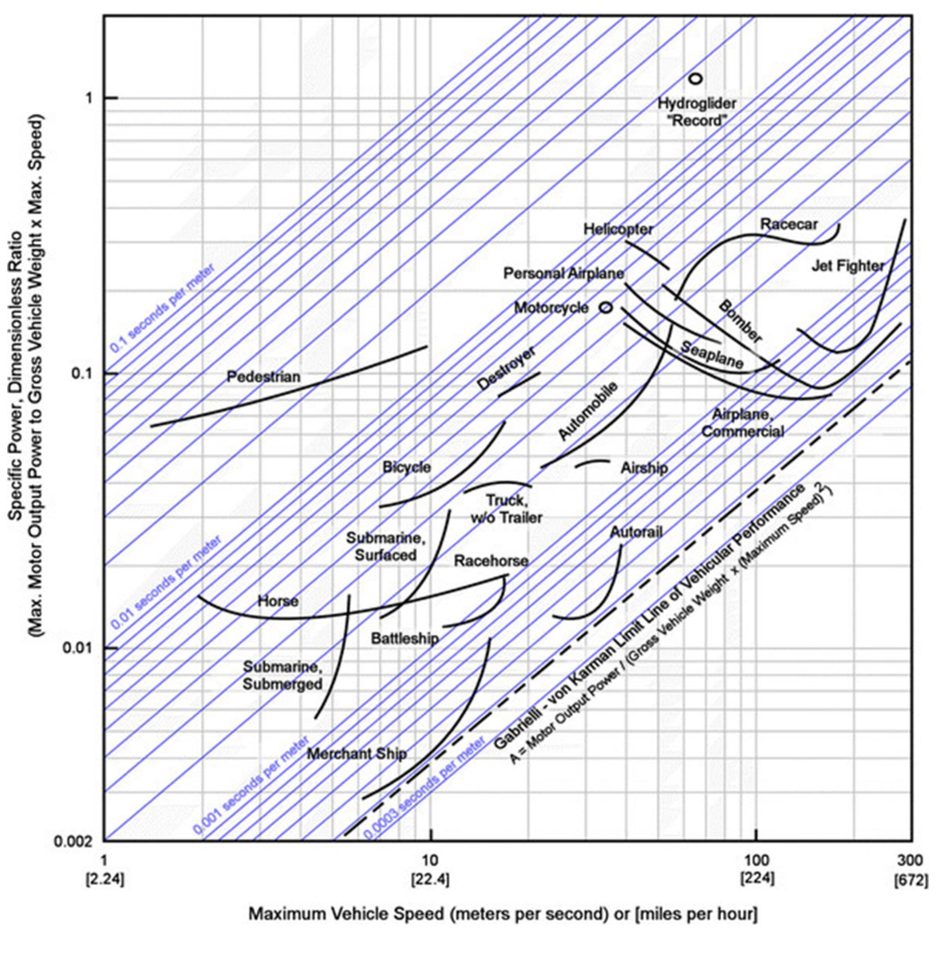

Figure 1: The original Karman-Gabrielli diagram as published by Trancossi (2016) in https://doi.org/10.1007/s40095-015-0160-6, plotting specific power versus maximum speed

Specific Power (Fig. 1)

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

Plot a „goodness“ parameter, G versus speed, V (Fig. 2, 4, 5). The „Figure of Merit“, is the product of G · V e. g.

$$a_{L/D} = L/D \cdot V$$

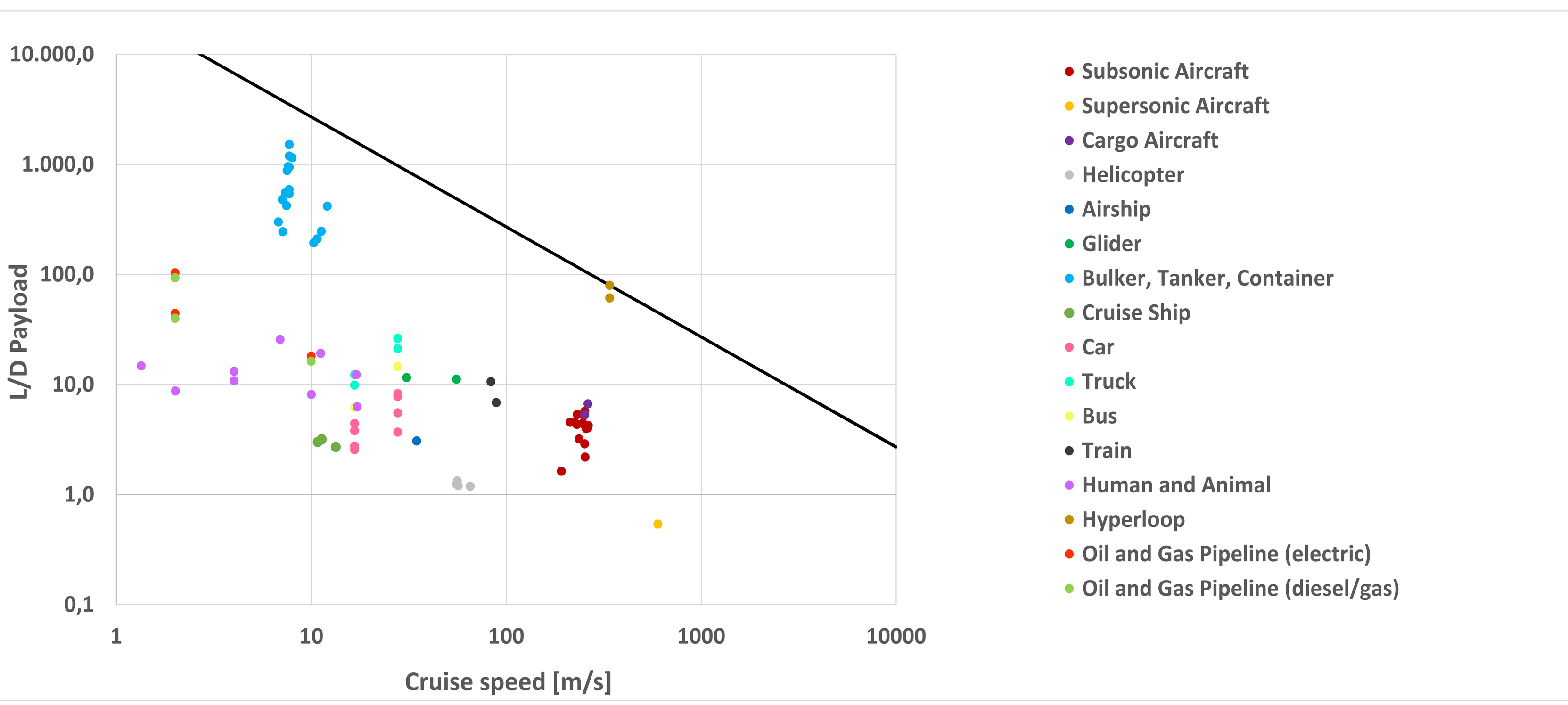

Figure 2: The Karman-Gabrielli diagram plotting lift(for payload)-to-drag ratio, L/D_payload versus cruise speed, V

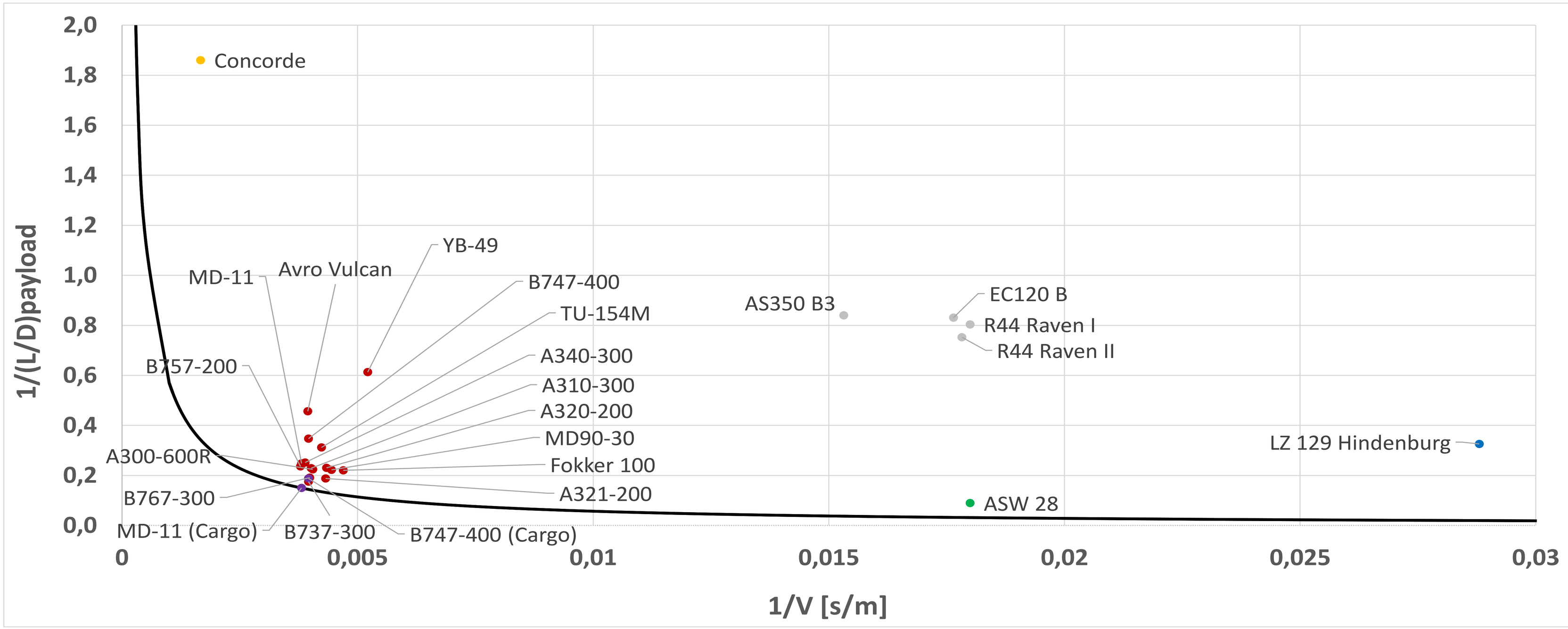

Figure 3: Karman-Gabrielli diagram plotting 1/(L/D)_payload versus 1/V with pareto front for aircraft

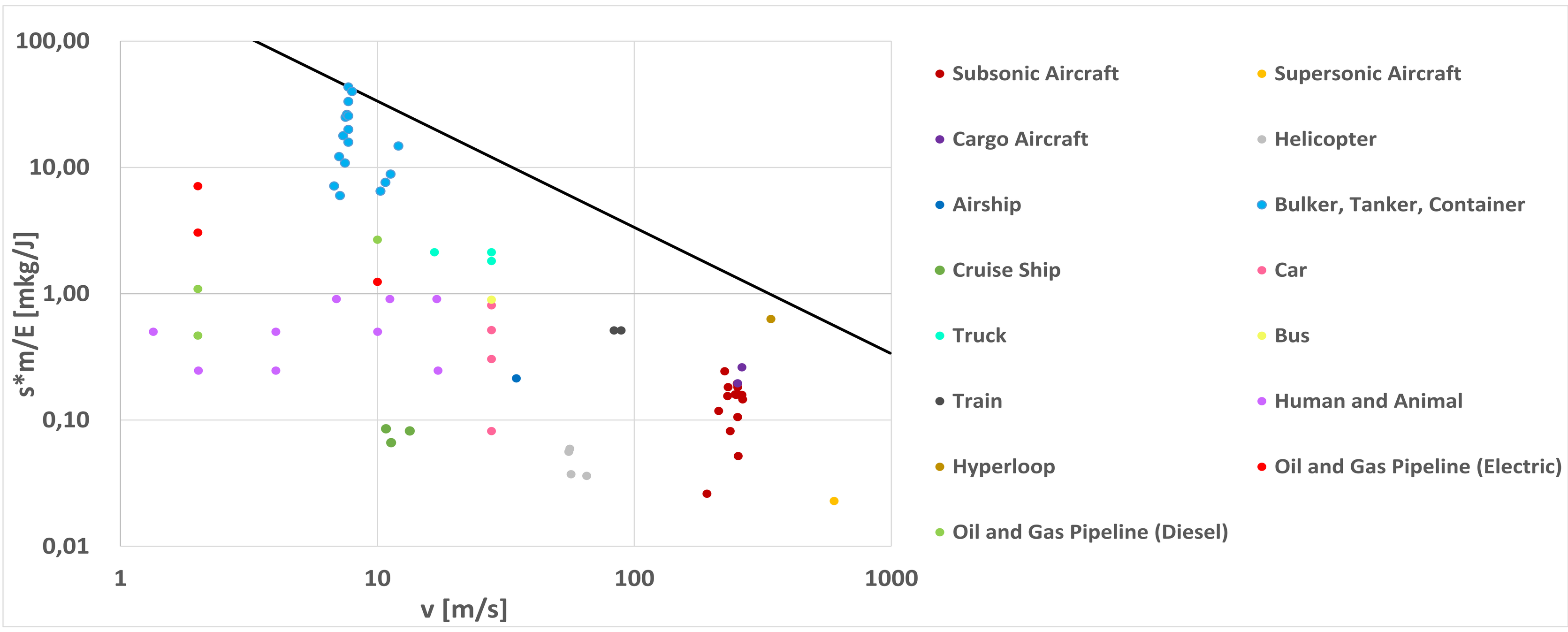

Figure 4: Karman-Gabrielli diagram plotting inverse of energy consumption per payload and range versus cruise speed, V

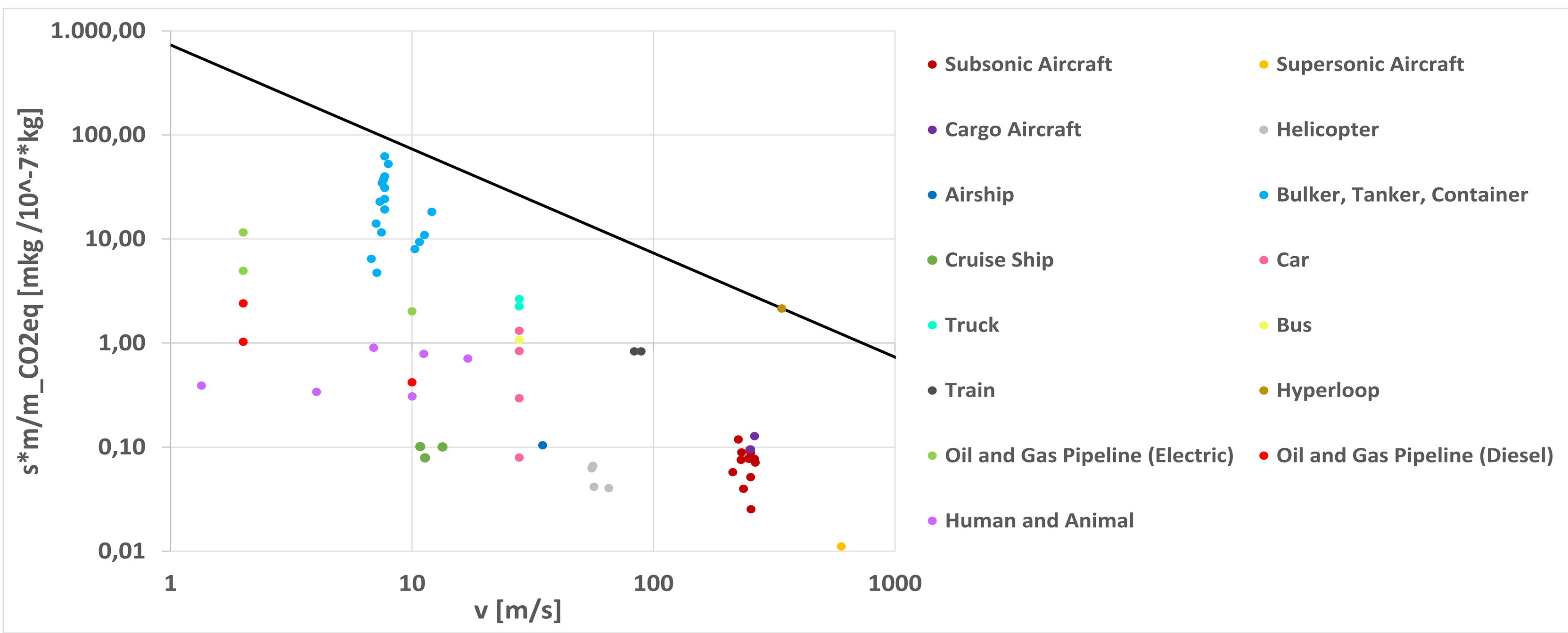

Figure 5: Karman-Gabrielli diagram plotting the inverse of equivalent CO2 mass per payload and range versus cruise speed, V

RESEARCH LIMITATION

This poster 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.

All details in the Bachelor Thesis of Putri (2023):
https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2023-04-20.015

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