Tunnel Visie: Lineaire Aandrijvingen in Buis-Transport en Achtbanen

dr. ir. André Veltman

Piak Electronic Design B.V.

19 juni 2019
1931 Congrescentrum 's-Hertogenbosch

POWER ELECTRONICS 2019

We Control Drives

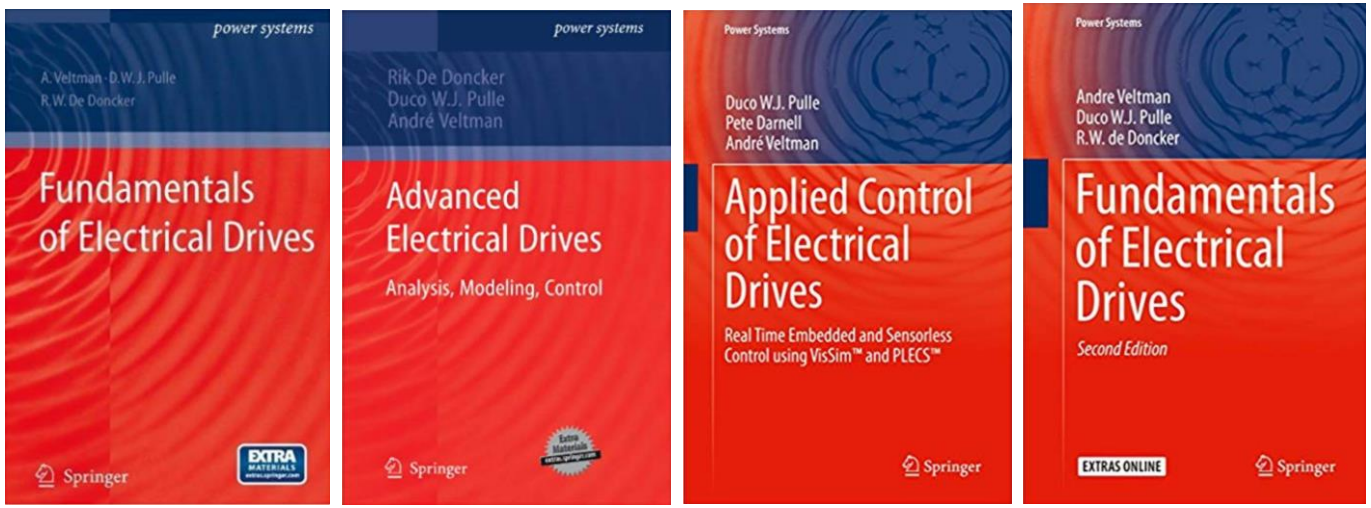
Korte geschiedenis

- Universiteit Twente (ir. elektrotechniek 1989)
- TU Delft (proefschrift `the Fish Method' 1994)
- TU Eindhoven (postdoc 1997)
- Piak opgericht in 1997

Projects:

- Dynamic systems
- Power electronics
- Motor control (senseless control, or self-sensing)

- books published:



Agenda

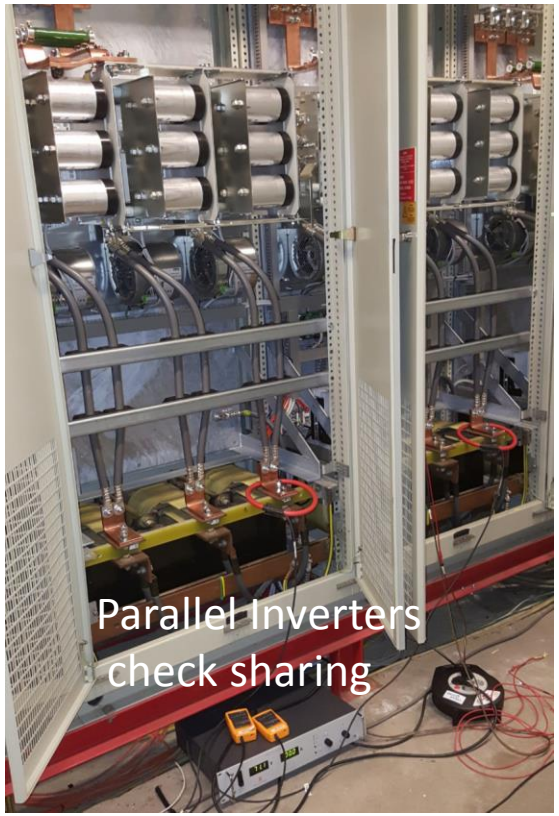
- Physics never lies
- Rollercoasters
- Tube-transport proposal

LSM-launch Rollercoaster main specs:

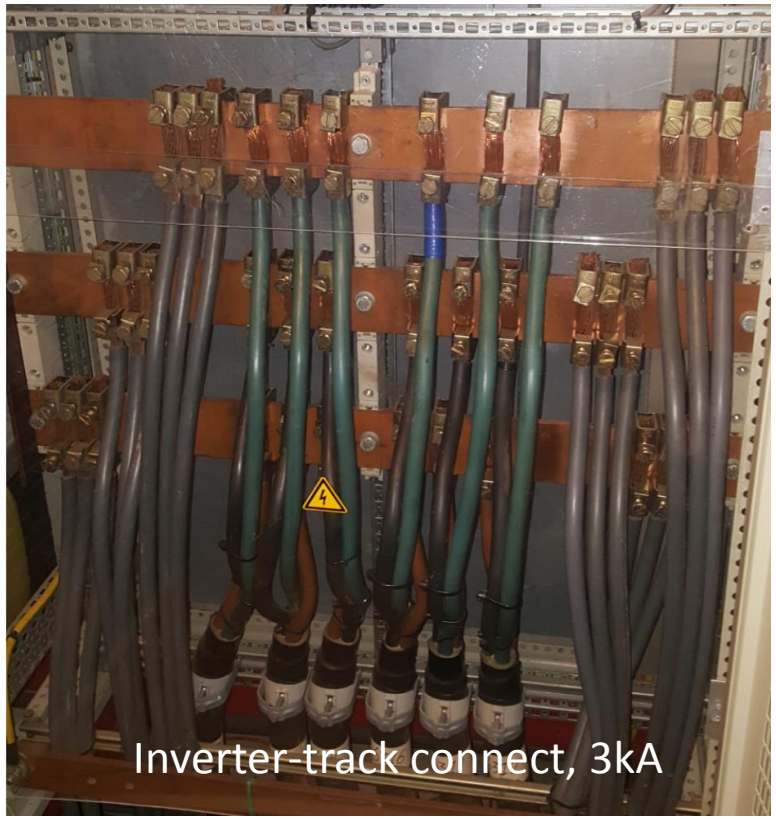
- 0-90km/h in 2.8s
- Switched long-stator
- 3000A(rms), 1000V, 0-125Hz
- 14ton, 15m/s^2

Power converter for LSM

3MVA by 3 parallel inverter modules



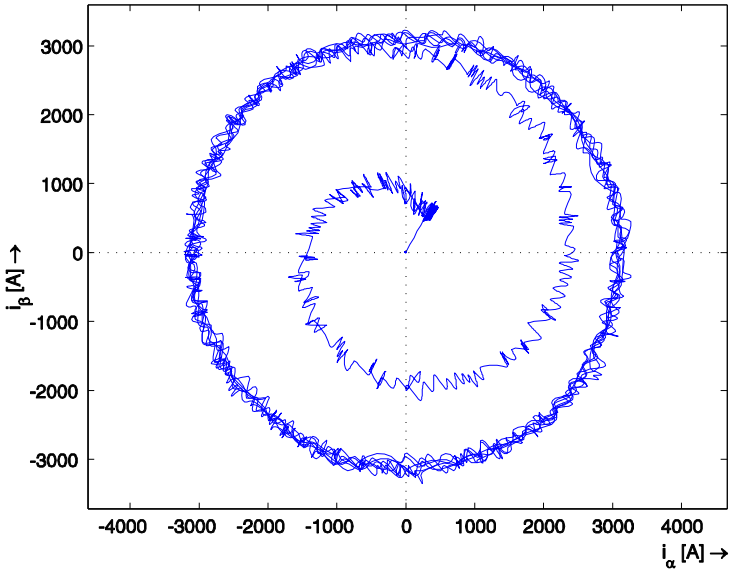
Parallel Inverters check sharing

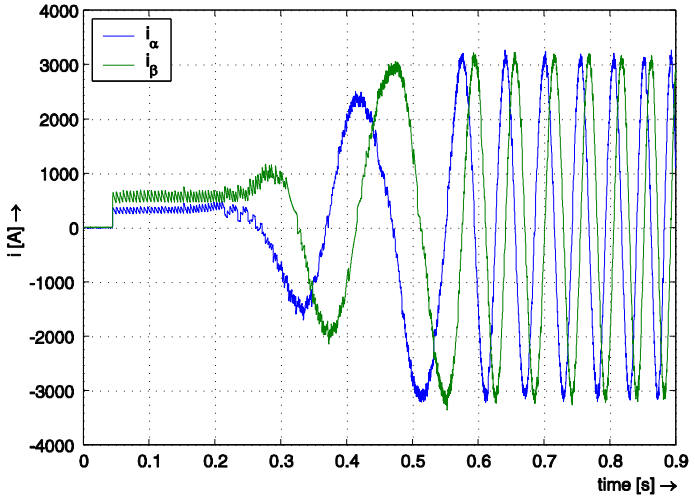


Inverter-track connect, 3kA

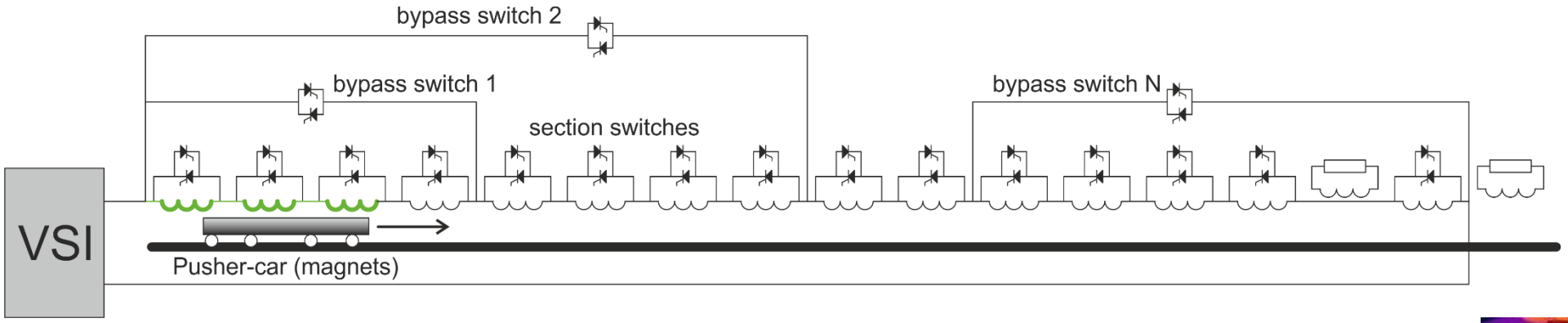
Final result

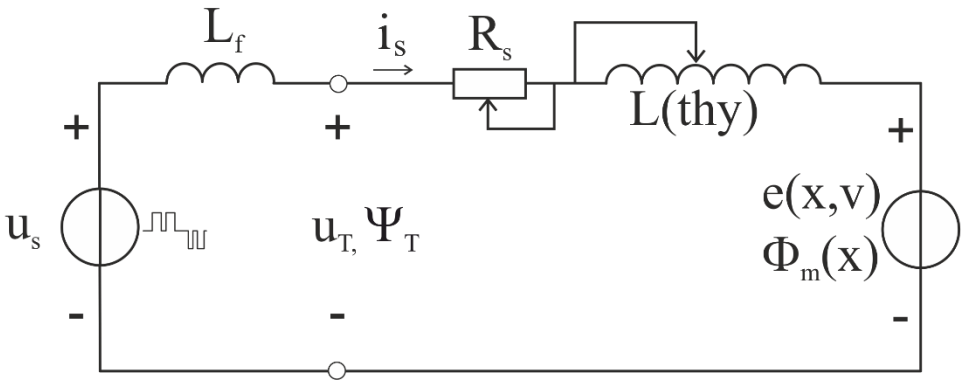
LSM pusher-car launch





LSM long-stator: equivalent circuit





Tube transport

- Energy and Drag
- Example of solar vehicle
- Suspension + propulsion
- Proposal
- Example trips
- Conclusions

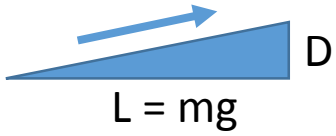
Energy & Drag

- Energy per distance **(J/m)= (Nm/m)** per item
- **(Nm/m) = N** Force (drag) per item

UNITS OF EFFICIENCY IN TRANSPORT

unit	equivalent
MJ/km	1000 N
Wh/km	3.6 N
kJ/(kg.km)	1 N/kg = 0.102 g
W/(km/h)	3.6 N
liter/100km	0.01 mm^2
liter/100km (fuel 40MJ/liter)	400 N
km/liter (fuel 40MJ/liter)	1/(40kN)
mile/Gallon	0.425 km/liter

- Drag/Lift ratio
- Goal: minimize **Drag**



$$\mathcal{F}_{\text{drag}} = \underbrace{mgC_{\text{susp}}}_{\mathcal{F}_{\text{susp}}} + \underbrace{\frac{1}{2}\rho\, A_{\text{front}} c_{\text{w}}\, v^2}_{\mathcal{F}_{\text{air}}}$$

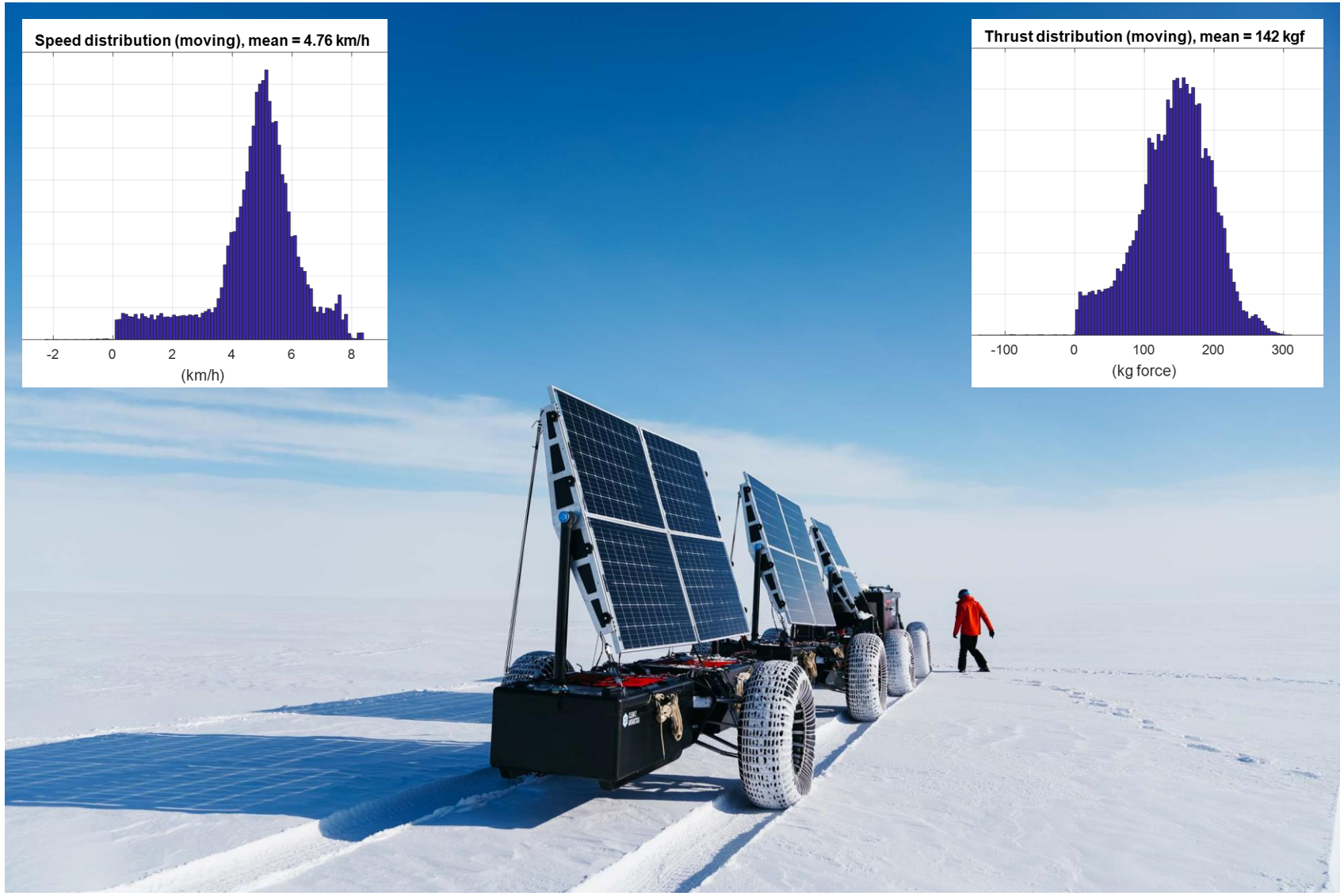
Antarctica expedition 2018

Rolling friction
10% of weight (1400kg):

D/L = 0.1

Specific power:
0…3W/kg

327kWh / 641km
0.51kWh/km = 1.84kN



Clean2Antarctica
Low-temp design

10 panels,
on-board 48V battery
4 wheel drive

4 Induction motors

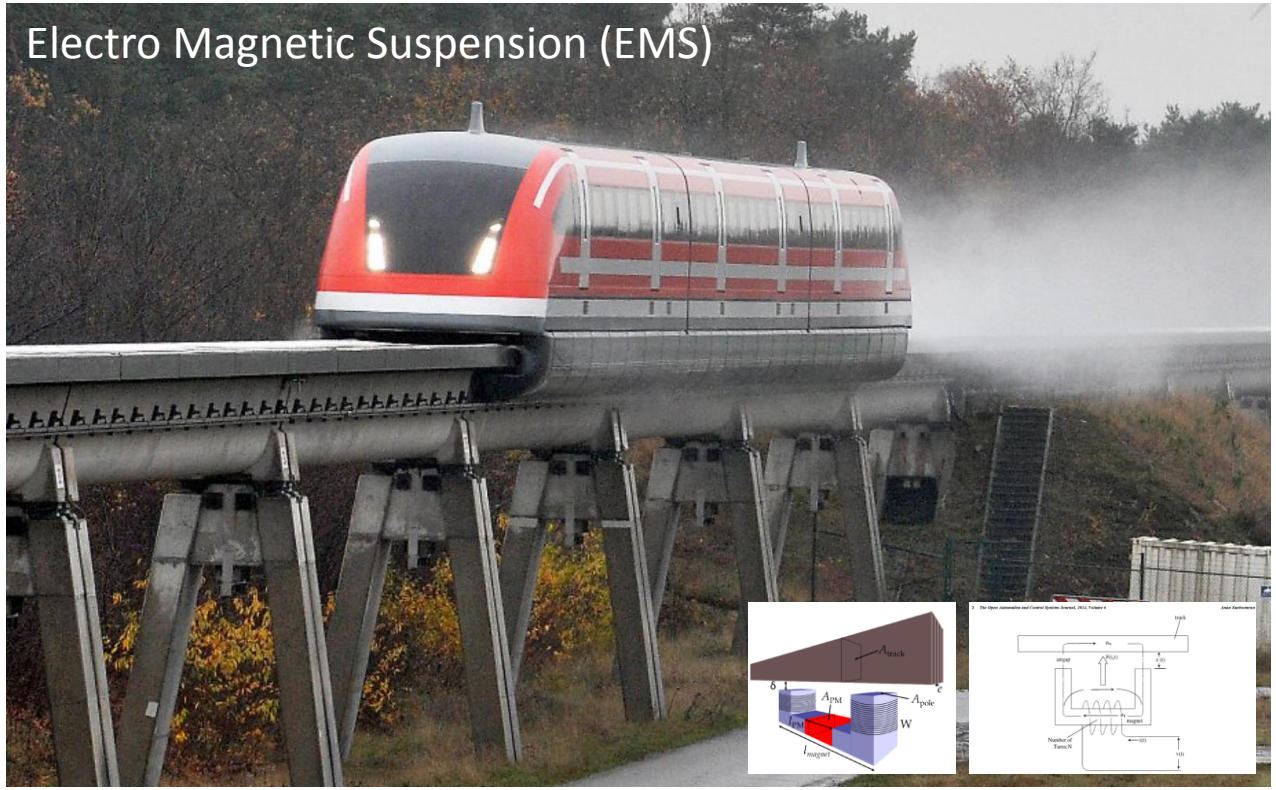
4 inverters

Suspension / levitation

- Rolling on Wheels
- Hover-craft
- Flying with wings or rotor blades
- Water jet or rocket
- Lighter than air

Magnetic suspension dragging on

Chuo SCmaglev, Japan: EDS
Lift-off speed and
High suspension drag in track: $\approx \dfrac{C_{\mathrm{eds}}}{\sqrt{v_{\mathrm{m}}}}$



Transrapid: EMS
Active control, low suspension drag $\approx a v_{\mathrm{m}} + b v_{\mathrm{m}}^2$

Why Maglev? Air-friction dominates drag

Figure from:
E. Fritz, J. Klühspies, R. Kircher, M. Witt, L. Blow, ``Energy Consumption of Track-Based High-Speed Trains: Maglev Systems in Comparison With Wheel-Rail Systems'', Transportation Systems and Technology. 2018;4(3 suppl. 1): 134-155.

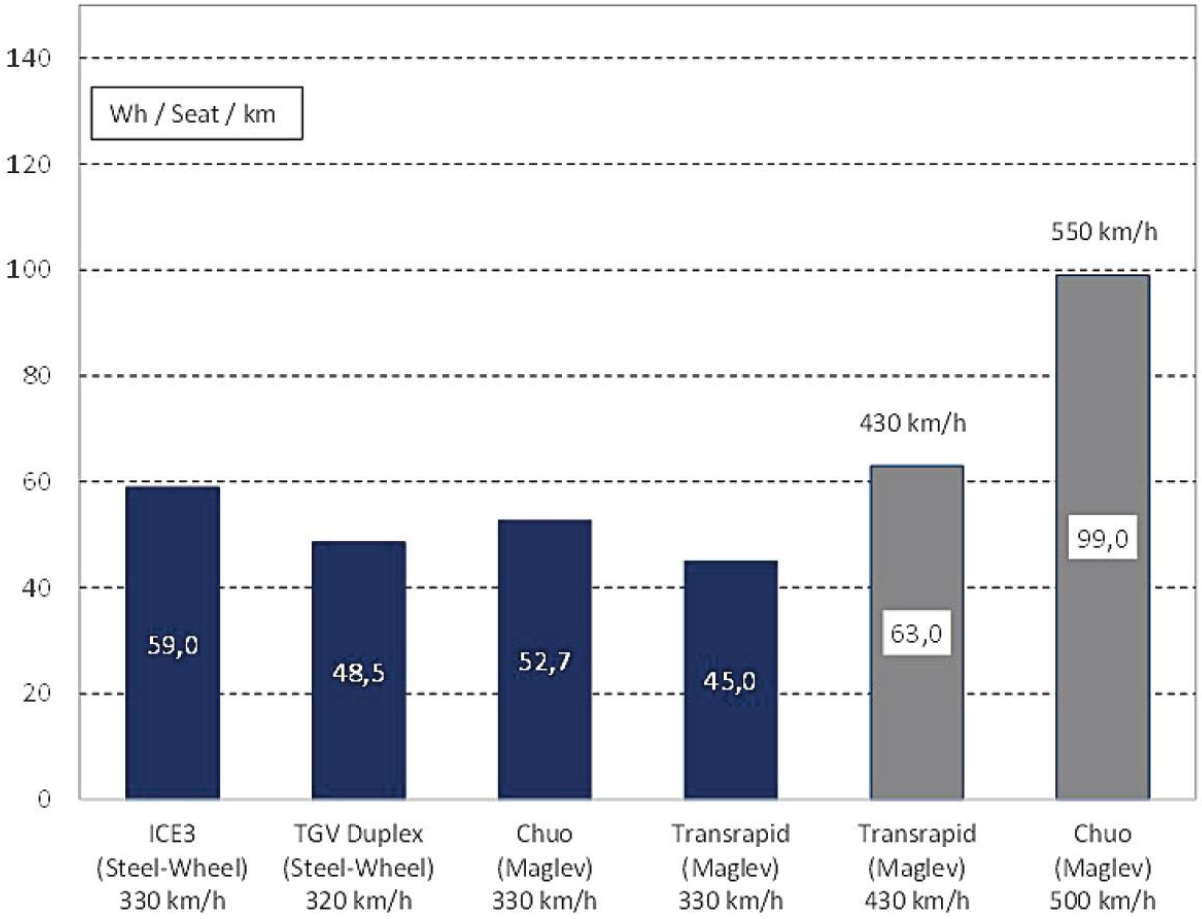
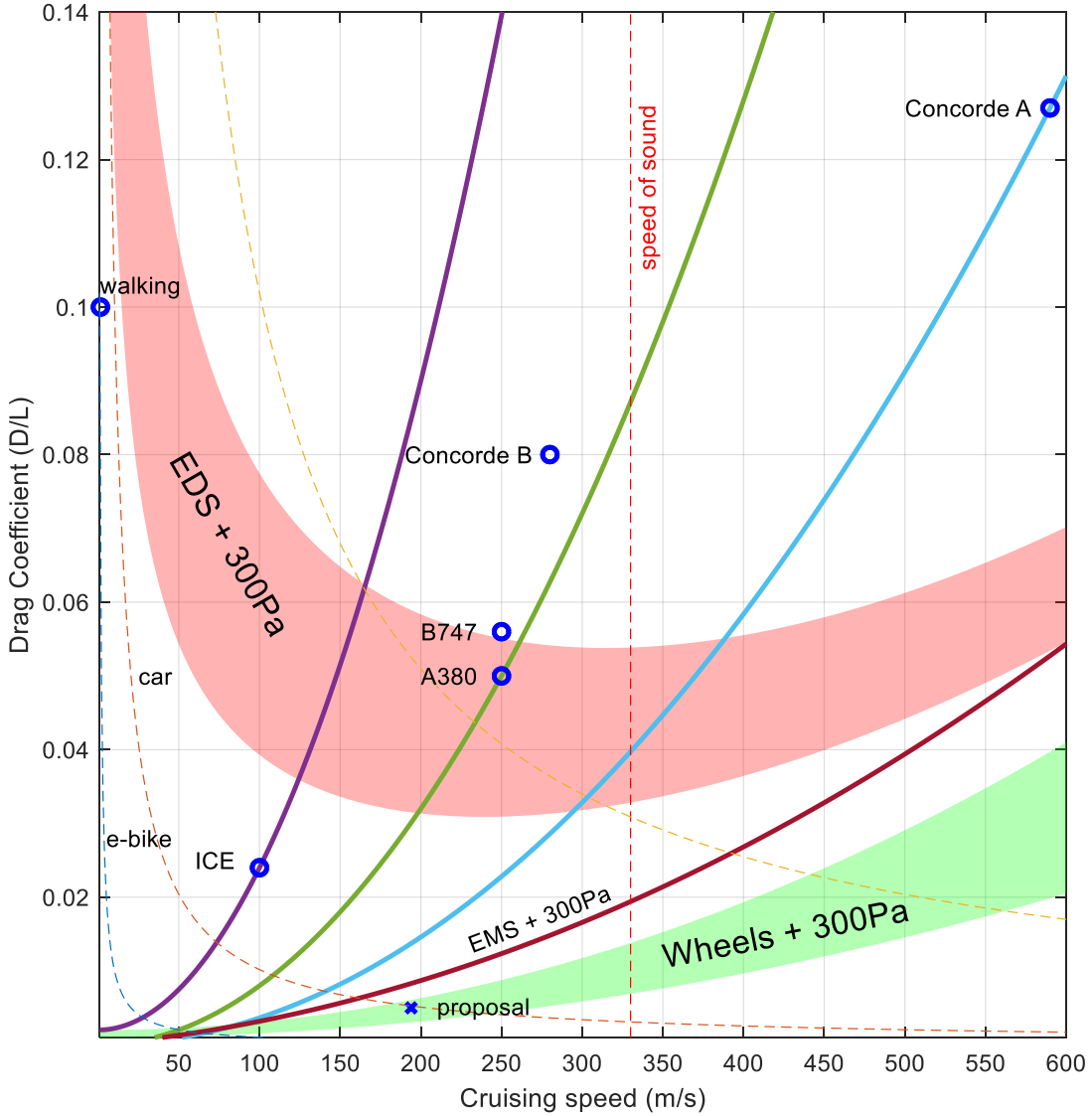
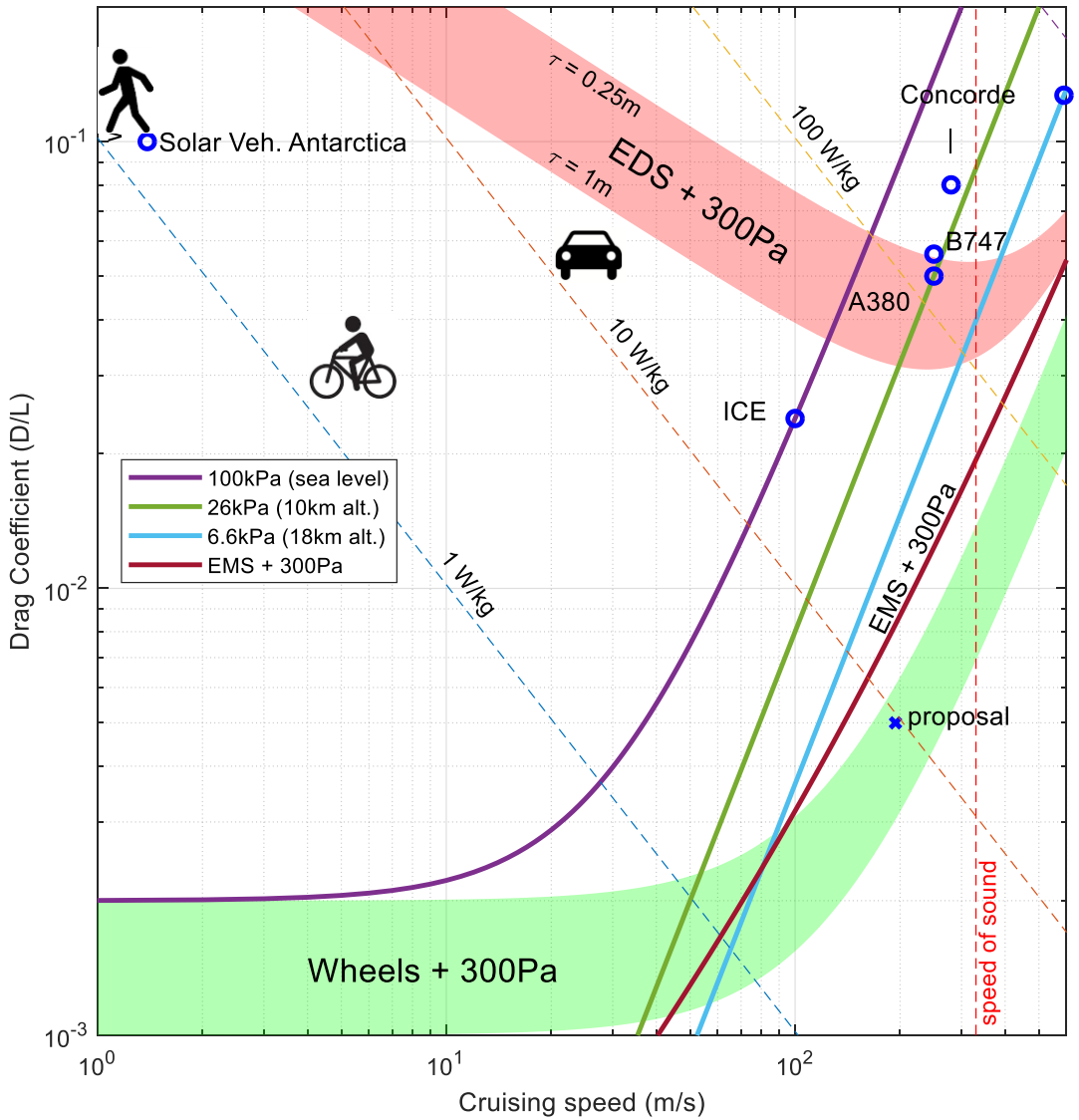


Fig. 4. Specific energy consumption in Wh per seat-km (Wh/Pl/km) at 330, 430 and 500 km/h (conventional representation)

Compare drag: linear and logaritimic

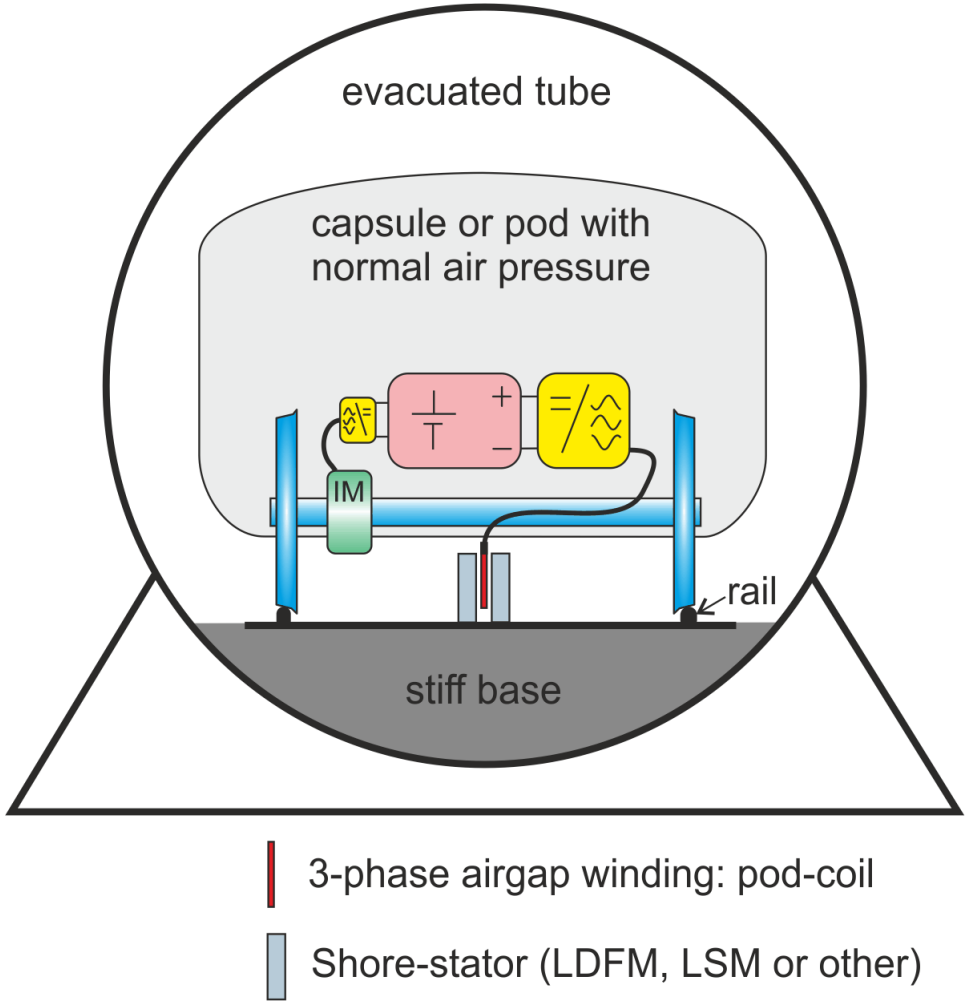
$$\mathcal{F}_{\text{drag}} = \underbrace{mgC_{\text{susp}}}_{\mathcal{F}_{\text{susp}}} + \underbrace{\frac{1}{2}\rho\, A_{\text{front}} c_{\text{w}}\, v^2}_{\mathcal{F}_{\text{air}}}$$



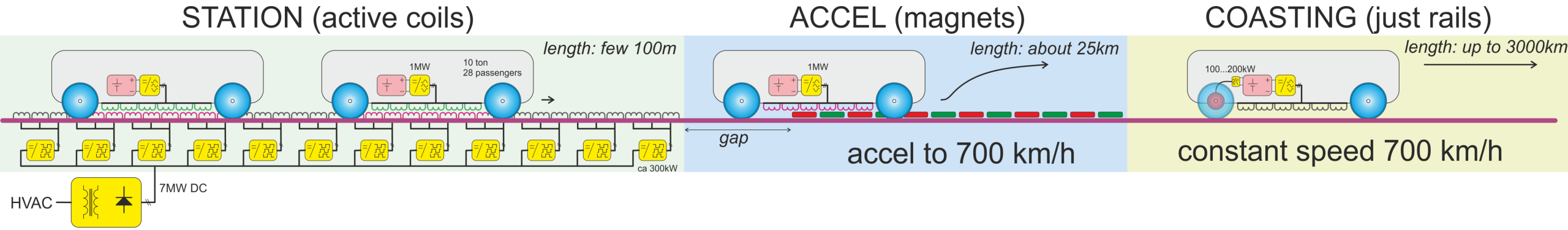


Proposal

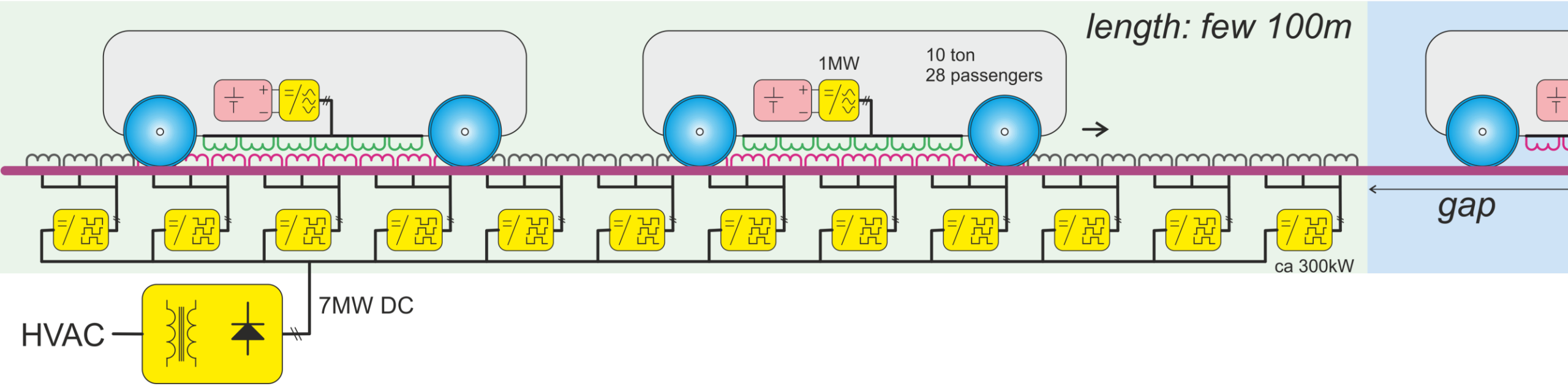
LiPo battery: 200Wh/kg
Drag = 0.5%
Range = 147km per %LiPo

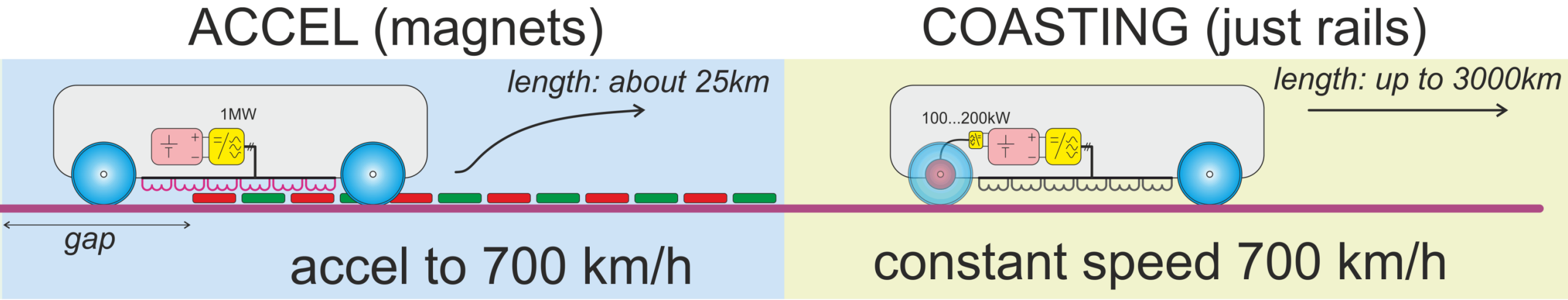


Proposal..

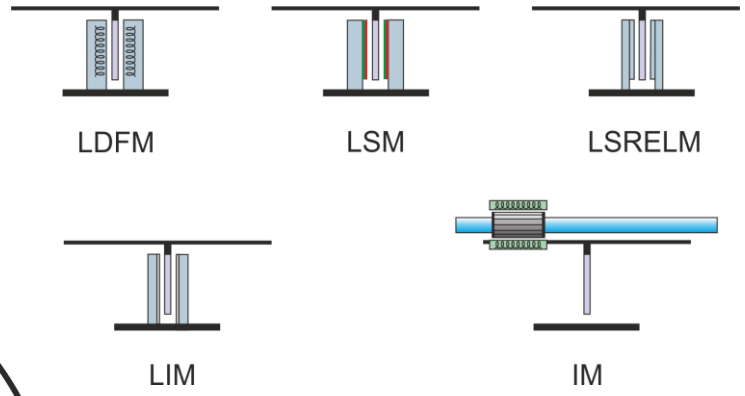

STATION (active coils)
ACCEL (magnets)
COASTING (just rails)
length: few 100m
1MW
10 ton
28 passengers
ca 300kW
7MW DC
HVAC
length: about 25km
1MW
gap
accel to 700 km/h
length: up to 3000km
100...200kW
constant speed 700 km/h

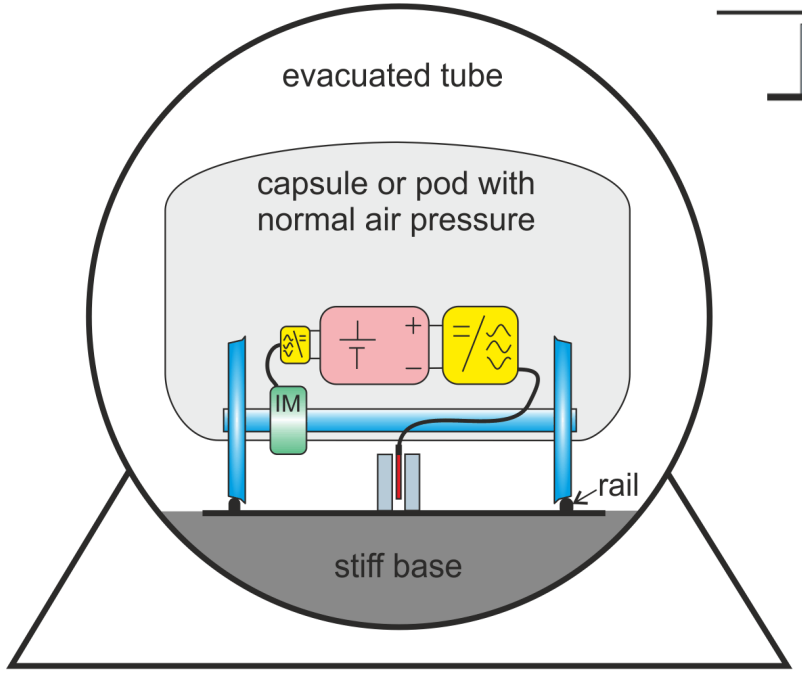
STATION (active coils)




ACCEL (magnets)
COASTING (just rails)
length: about 25km
1MW
gap
accel to 700 km/h
length: up to 3000km
100...200kW
constant speed 700 km/h

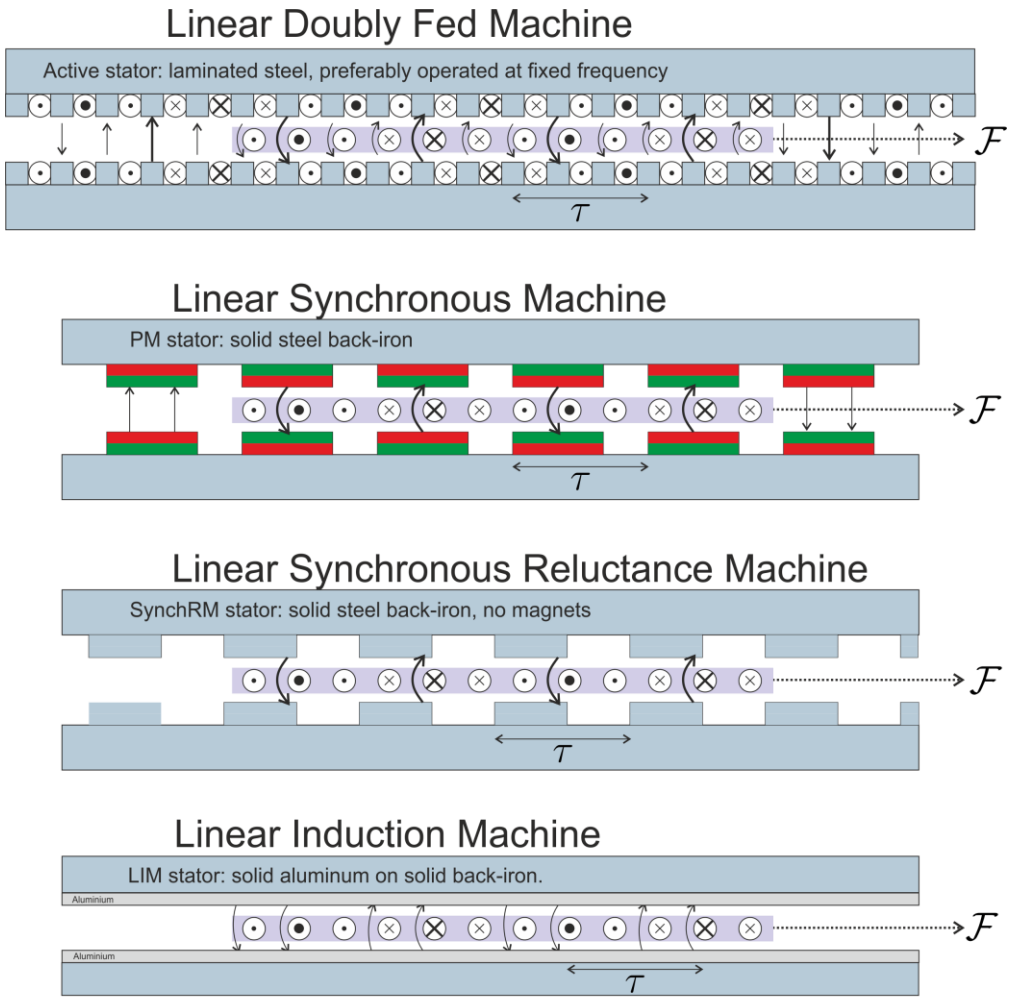
Proposal…





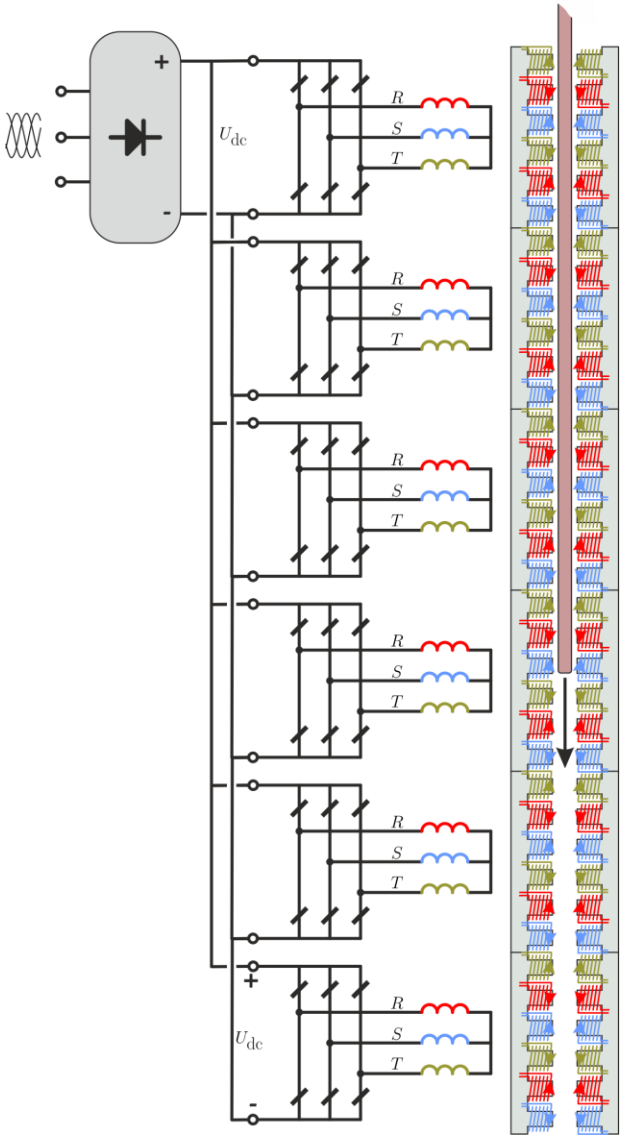
3-phase airgap winding: pod-coil

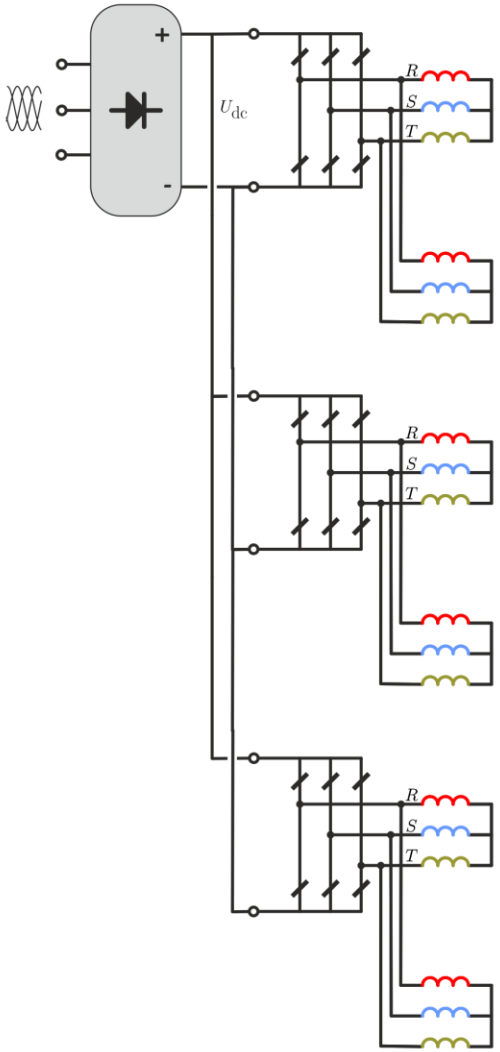
Shore-stator (LDFM, LSM or other)

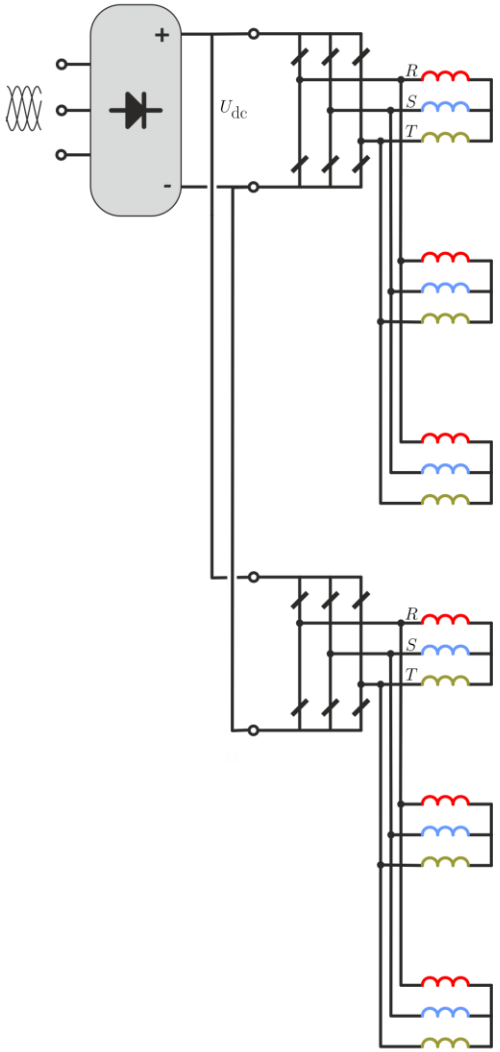


Active ironless mover supplied from inverter and battery inside capsule. Litz wire coils are recommended.

Shore converters

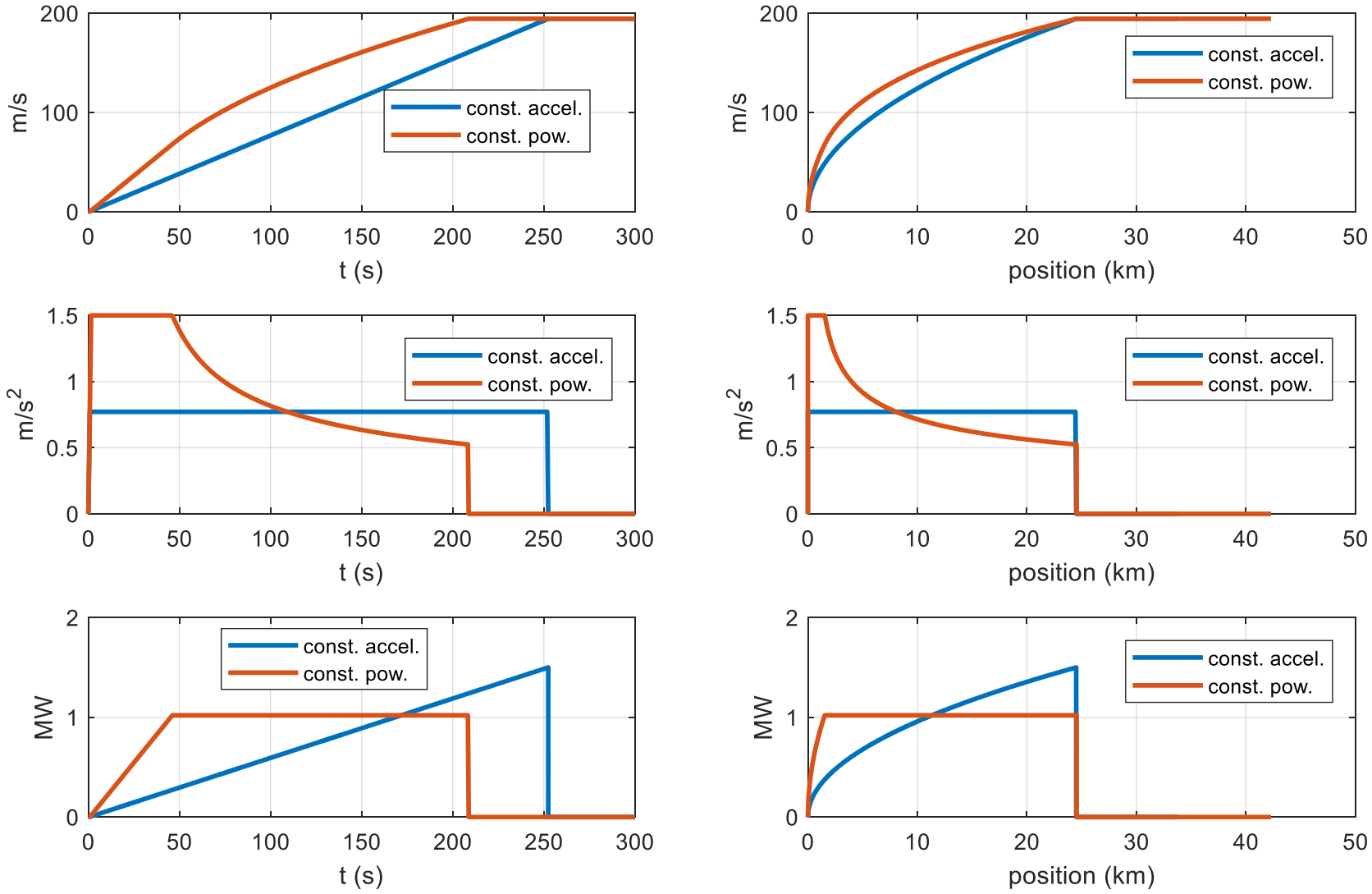






Constant power or constant acceleration?

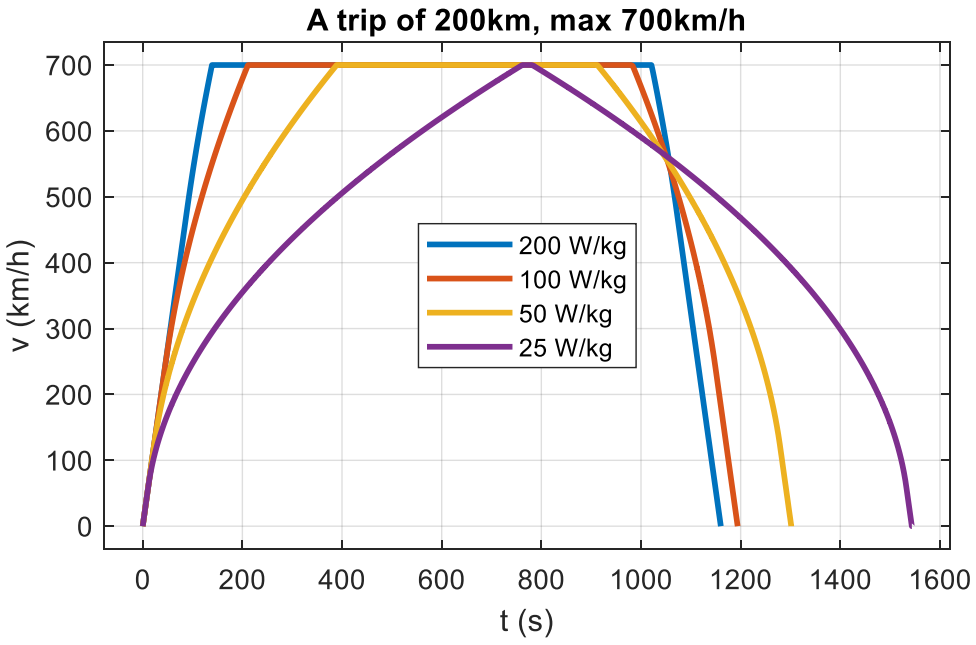
Vehicle: 10000kg, 0..700km/h in 24.5km

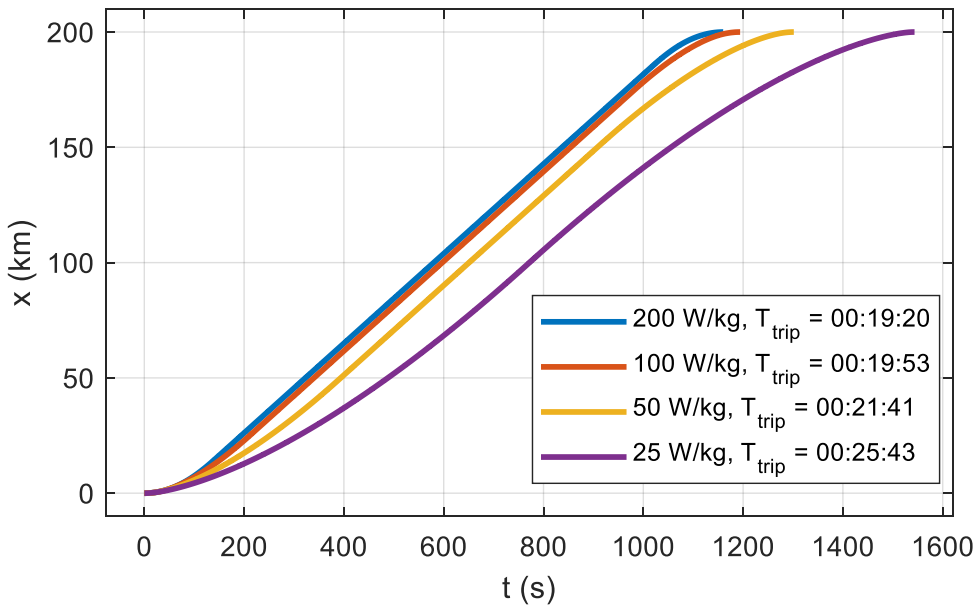


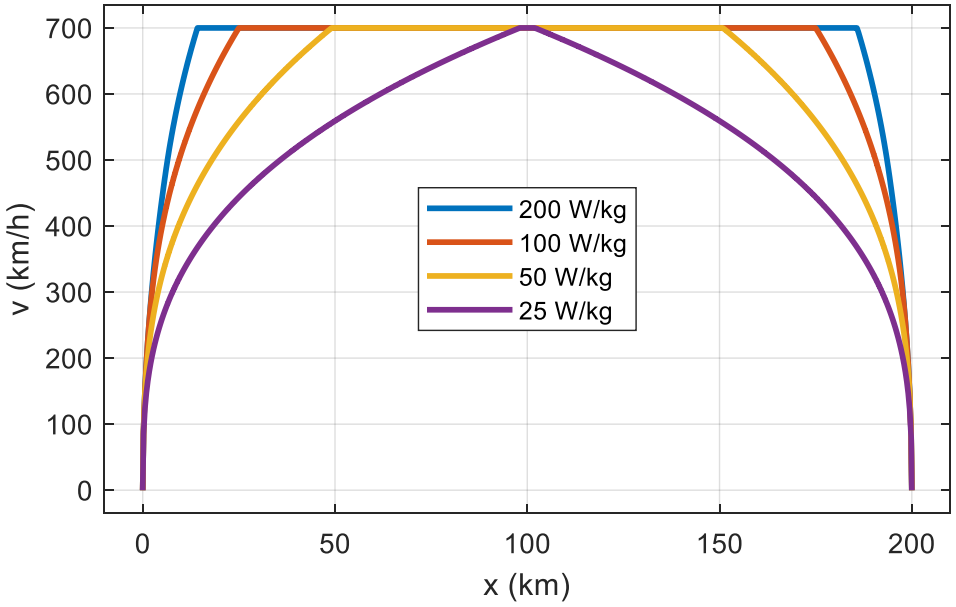
$$\Psi_{\text{total}} = \int_0^{x_{\text{final}}} \frac{\Psi_{\text{stator}}(x)}{l} \mathrm{d}x$$

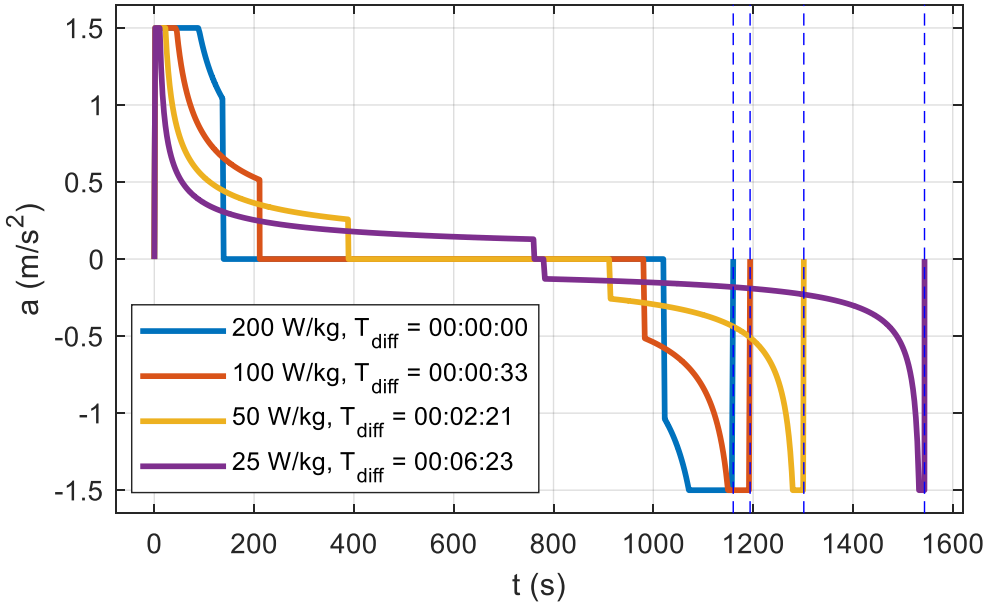
$$\Psi_{\text{total}} = \frac{\frac{1}{2} m_{\text{pod}}\, v_{\text{final}}^2}{l\, n i}$$

200km short trip

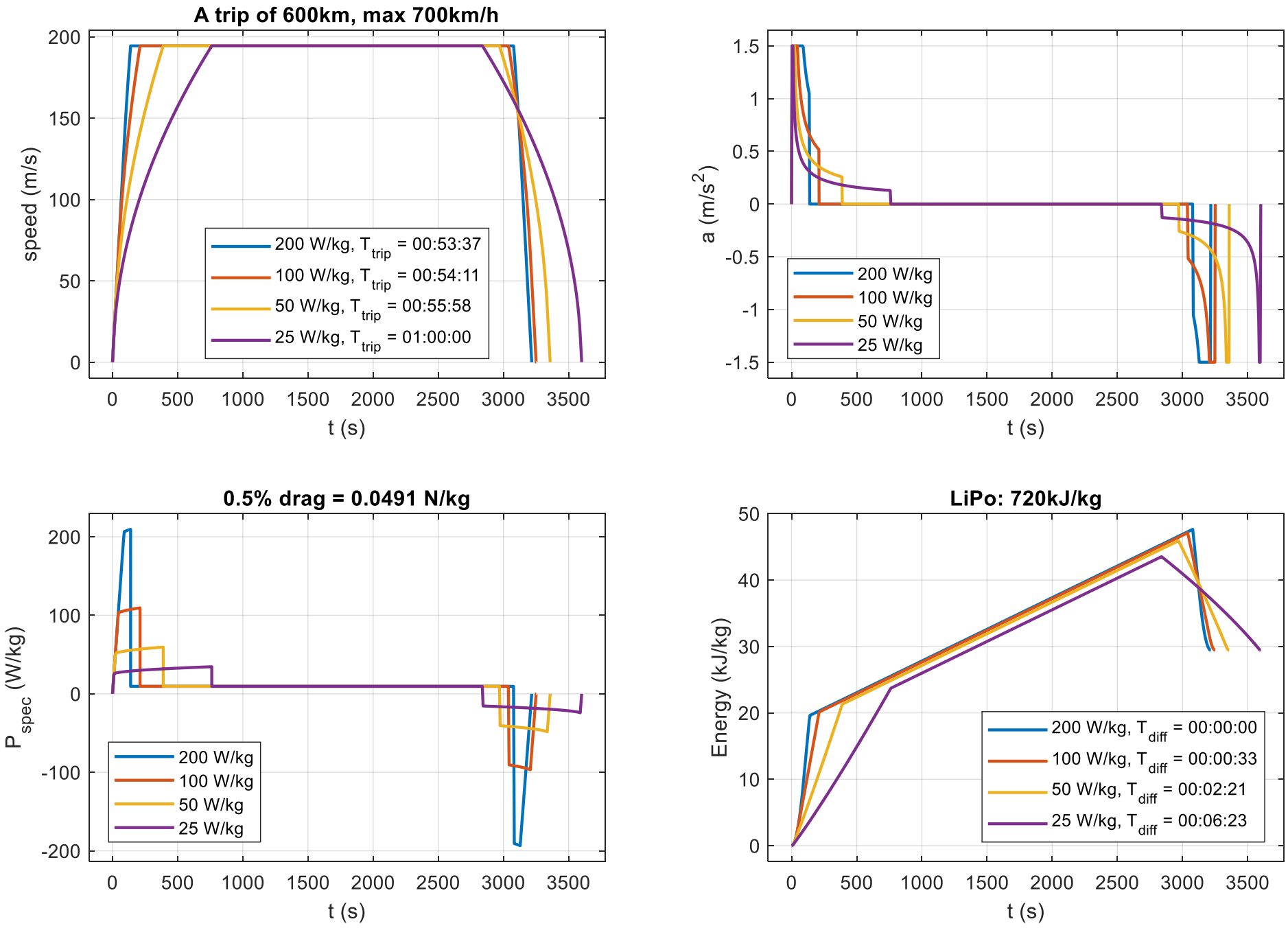






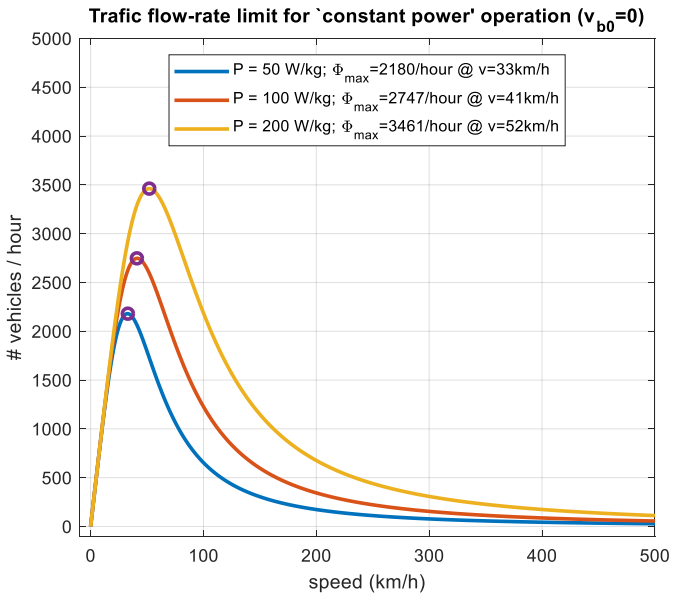


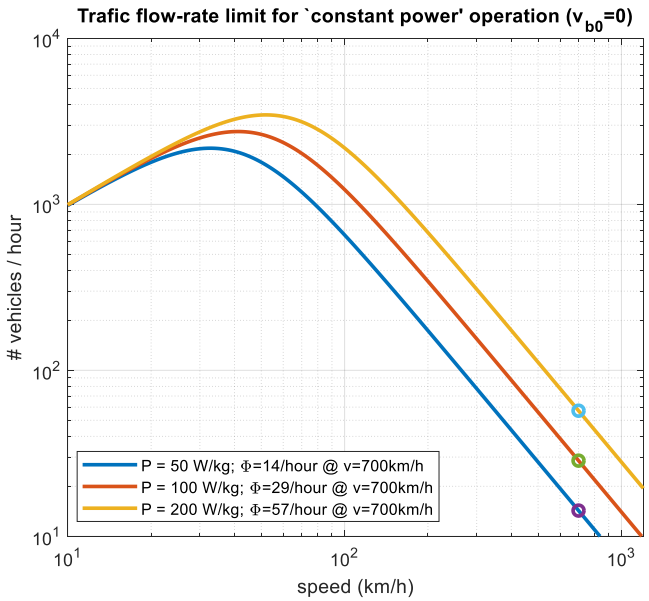
600km trip


A trip of 600km, max 700km/h
speed (m/s)
t (s)
200 W/kg, T trip = 00:53:37
100 W/kg, T trip = 00:54:11
50 W/kg, T trip = 00:55:58
25 W/kg, T trip = 01:00:00
a (m/s2)
200 W/kg
100 W/kg
50 W/kg
25 W/kg
0.5% drag = 0.0491 N/kg
P spec (W/kg)
LiPo: 720kJ/kg
Energy (kJ/kg)
200 W/kg, T diff = 00:00:00
100 W/kg, T diff = 00:00:33
50 W/kg, T diff = 00:02:21
25 W/kg, T diff = 00:06:23

Traffic and safety: make trains of pods

Energy < 10 Wh/km/passenger





EXAMPLE PERFORMANCE OF ACTIVE POD ON WHEELS.

Item	value	unit
Trip distance	600	km
Cruise speed	700	km/h (194m/s)
Pod-payload	28	pass.
Pod-mass loaded	10000	kg
Kinetic energy	52	kWh (188MJ)
Travel time	0:55	hour (time while moving)
Battery-mass (LiPo)	1000	kg (10%), 200kWh
Pod-power	1000	kW (100W/kg)
Air pressure in tube	< 300	Pa
Accel distance	24.5	km
Accel time	3:32	min
Charging time	7	min (2 trains in station)
Energy per trip	82	kWh
Station power	7000	kW (on each end)
f pod	-300...970	Hz (pole-pitch $\tau = 0.1$ m)
f shore-stator	300	Hz or other constant value
LDFM length	2×150	m (2 trains in station)
LSM length	$< 2 \times 25$	km (partial LSRELM?)
IM length	551	km
wheel diameter	1	m (rough estimate)
wheel and IM speed	3700	rpm @ 700km/h
drag force	200...500	N ($C_{susp} = 0.002...0.005$)
IM torque	100...250	Nm
IM power	40...100	kW (4...10W/kg)
pod length	15	m
coil height	0.15	m
max thrust	15	kN (@ 1.5m/s^2)
max tangential stress	0.7	N/cm^2 (7 kPa)
train length	5	pods (total 140 passengers)
Launches/hour	17	Safe distance (24.5km)
flow	2380	passengers / hour
e-milage	$\approx 3..10$	Wh/km per passenger

Conclusions

- No superconductors, no long-stator active tracks, no magnetic levitation and no high acceleration necessary for efficient tube-transport.
- Drag losses in maglev systems are significant.
- Remove air: minimal drag -> energy low -> on board storage OK.
- Simplicity, cost, efficiency and safety all benefit from proposal.

Contactgegevens

- Bedrijfsnaam: Piak Electronic Design B.V.
- Adres: Markt 13, Culemborg
- Telefoonnummer: 0345-534126
- E-mailadres: a.veltman@piak.nl
- Website www.piak.nl