2nd Workshop on Innovative Engineering for Fluid Power:
Applications in Aircraft, Vehicles and Energy (Wind, Hydroelectricity, and Oil and Gas)

WIEFP 2014

Technologies for Vehicular Energy Efficiency

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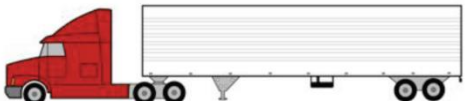
Outline

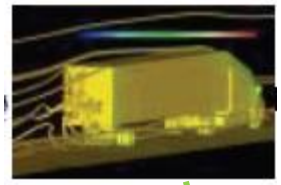
1. Why energy efficiency for trucks
2. The waste
3. Strategies of energy recuperation
4. A hydraulic-pneumatic alternative
5. Conclusion

Powertrain efficiency



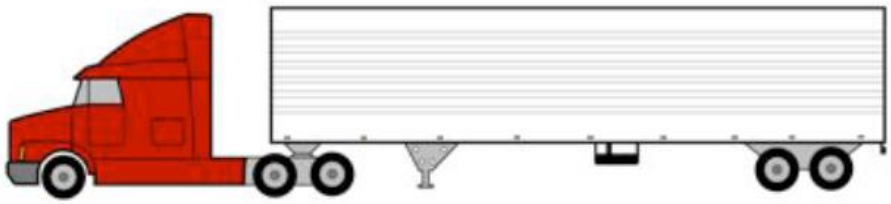
Energy dissipated in steady state: Class 8 long-haul

Tank → Wheel



	Fuel		42%		38%		37%		36%		23%	
Available, kW	380		160		145		141		137		86	
Component		Engine		Auxiliary		Transmission		Driveline		Tires		Drag
Losses, kW		220		15		4		4		51		86
Efficiency, nond.		42%		38%		97%		97%		63%		

Vehicle efficiency



		Passenger car	**Truck**
Vehicle weight, kg		1500	13608
Useful weight, kg		75	20412
Ratio useful/vehicle		0.05	1.5
Efficiency	Tank-to-Wheels	13%	23%
Energy loss	Drag	7%	7%
	Acceleration	6%	16%
Fraction useful energy		0.3%	24%

23%

Fraction of energy actually used to move the useful cargo

Why is efficiency important?

Annual energy consumption in Brazil (2011):

- Primary energy = 229 Mtoe

  18 % electricity + 82 % thermal
- Transport = 74 Mtoe = 32 % of total
- Diesel oil = 34 Mtoe = 46 % of transport

(more than total in Chile)

To put in context:

- Record generation of Itaipu (2010) = 8.5 Mtoe

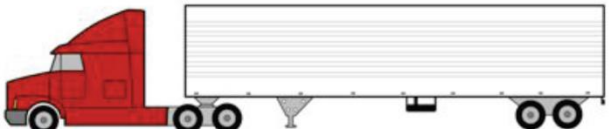
➔ 4 Itaipus-equivalent burned as diesel oil annually

Approach to improve vehicle efficiency

Efficiency = ton x km/liters

Three-steps strategy:

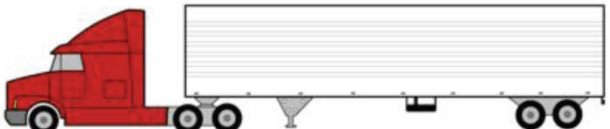
1. **Reduce vehicle weight, losses and other energy needs:**
   - **Reduce air drag and rolling resistance**
   - **Reduce weight**
   - **Reduce idling time**
   - **Reduce cabin heating/cooling loads**
2. **Increase efficiency and downsize the powertrain:**
   - **Increase power train efficiency**
   - **The smallest powertrain needed for the job**
   - **Recover waste energy**
3. **Increase load capacity:**
   - **Increase cargo volume – long-combination vehicle**



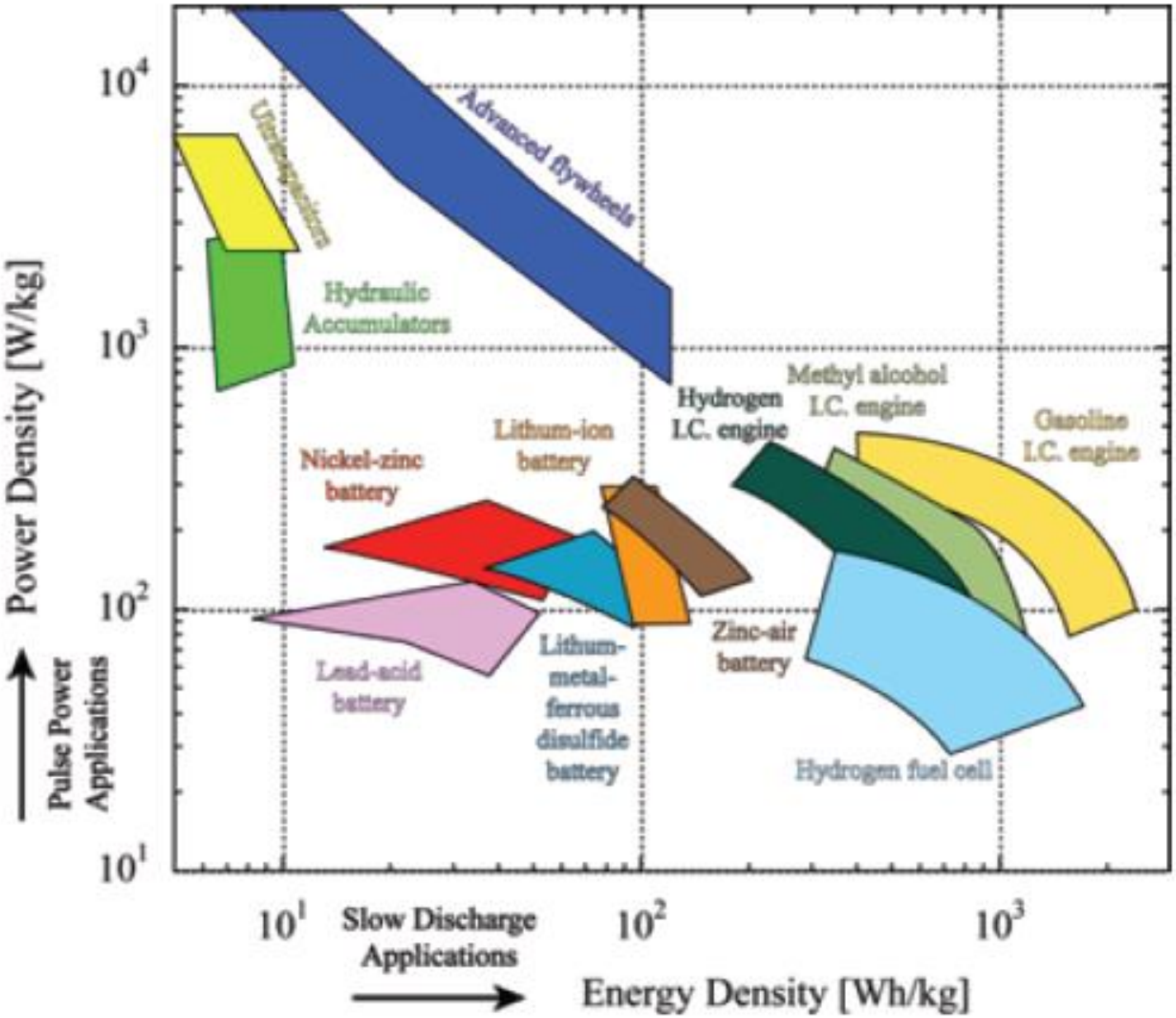
Recover waste energy

Hybrid systems:

1. **Thermal (internal combustion engine) – Limited by Carnot´s Cycle**
2. **Mechanical – No theoretical limit**
3. **Electrical**
4. **Hydraulic/pneumatics – Limited by heat transfer**



Hybrid systems



Key Distributed Power Program Quarterly Review (2001)

Hydraulic/pneumatics versus Electric

Hydraulic/pneumatics:

Advantages

- Increased energy density
- Enlarged energy range
- Pneumatic accumulator is cleaner

Disadvantages

- Small energy density / larger sizes of accumulator
- Lower thermal efficiency of the accumulator
- Internal combustion engine does not easily work as a compressor

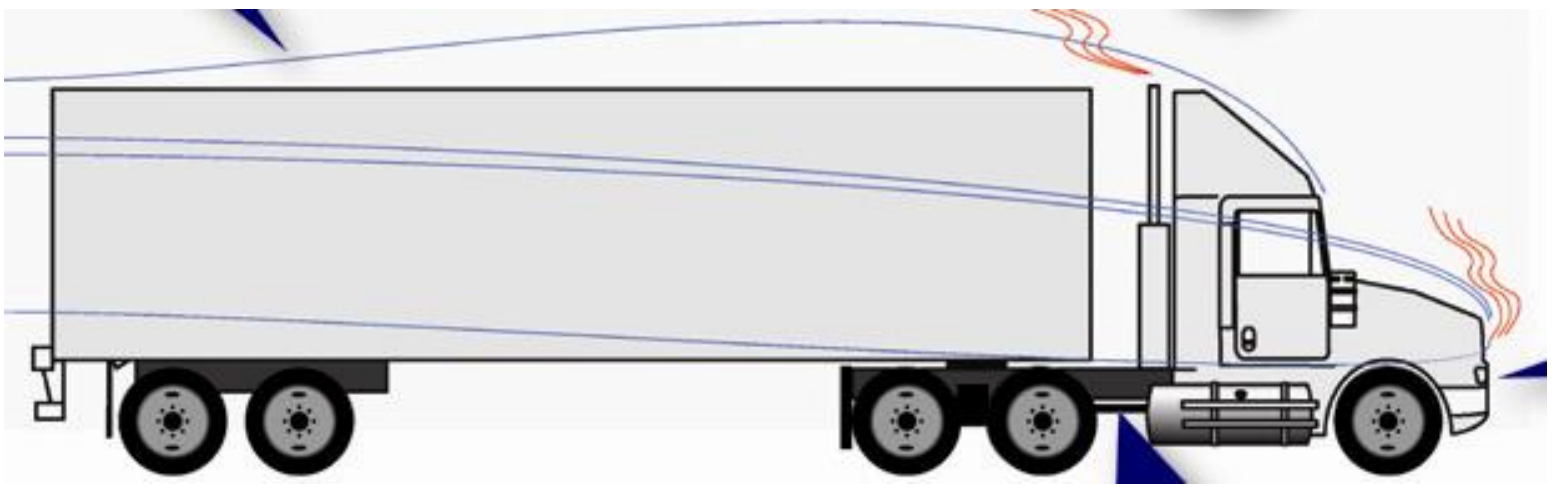
Simulation - Vehicle dynamics

Dynamics:

$$F_t - F_A - F_R - F_f - F_G = m_v \frac{dv_v}{dt}\left(1 + \frac{J_{eq}}{m_v\, {r_w}^2}\right)$$

Drag:

$$F_A = \frac{1}{2}\, \rho_{ar}\, (\dot{x}_v)^2\, A_f\, C_{D,A}$$



Rolling: $F_R = m_v\, g\, C_R\, cos\alpha$

Description of the hybrid system

Objectives:

Energy storage during:

- Breaking when needed
- Keeping the speed while descending

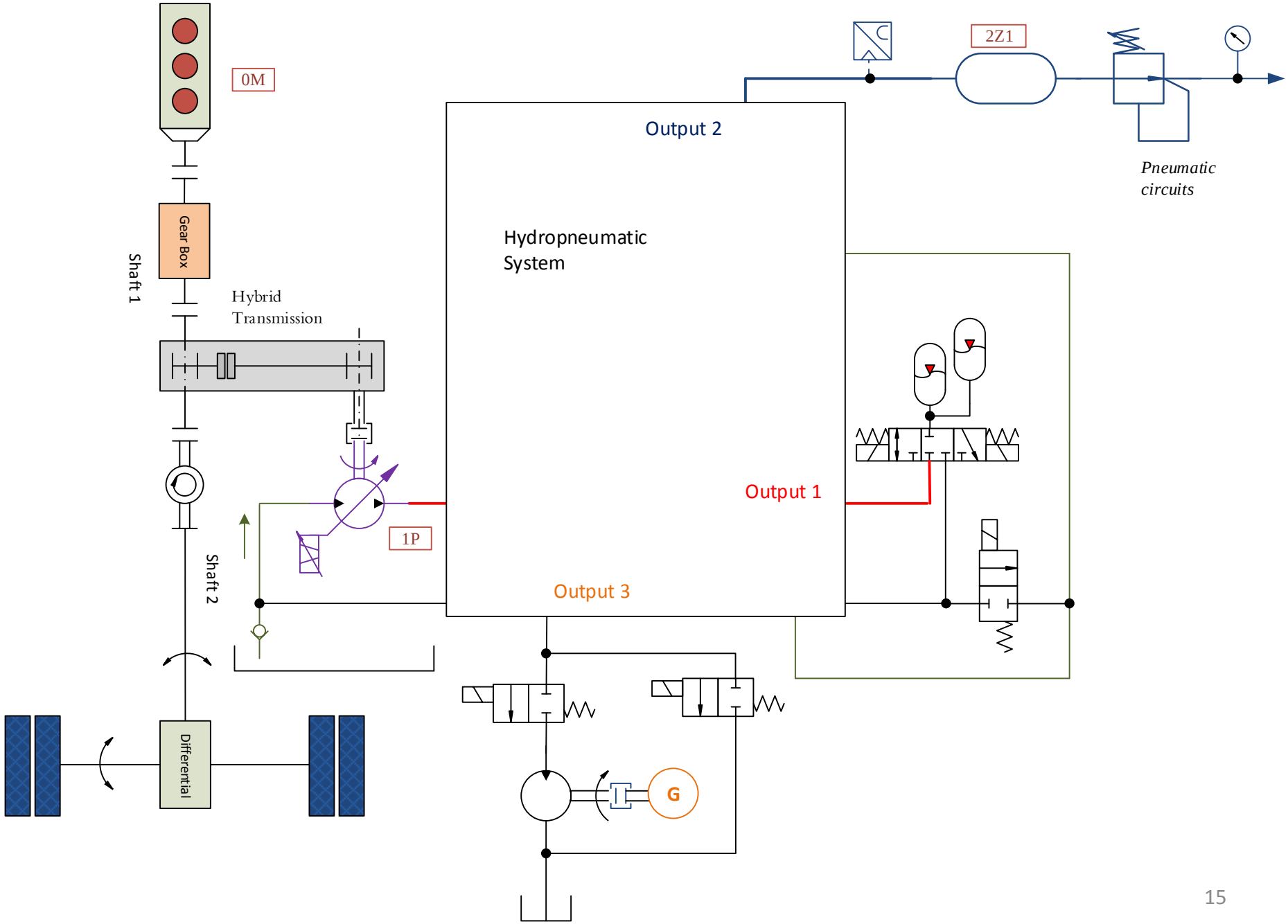
Use of stored energy for:

- Compressing air for auxiliaries
- Acceleration
- Other auxiliaries using a hydraulic pump

Description of the hybrid system

Modes of energy recovery:

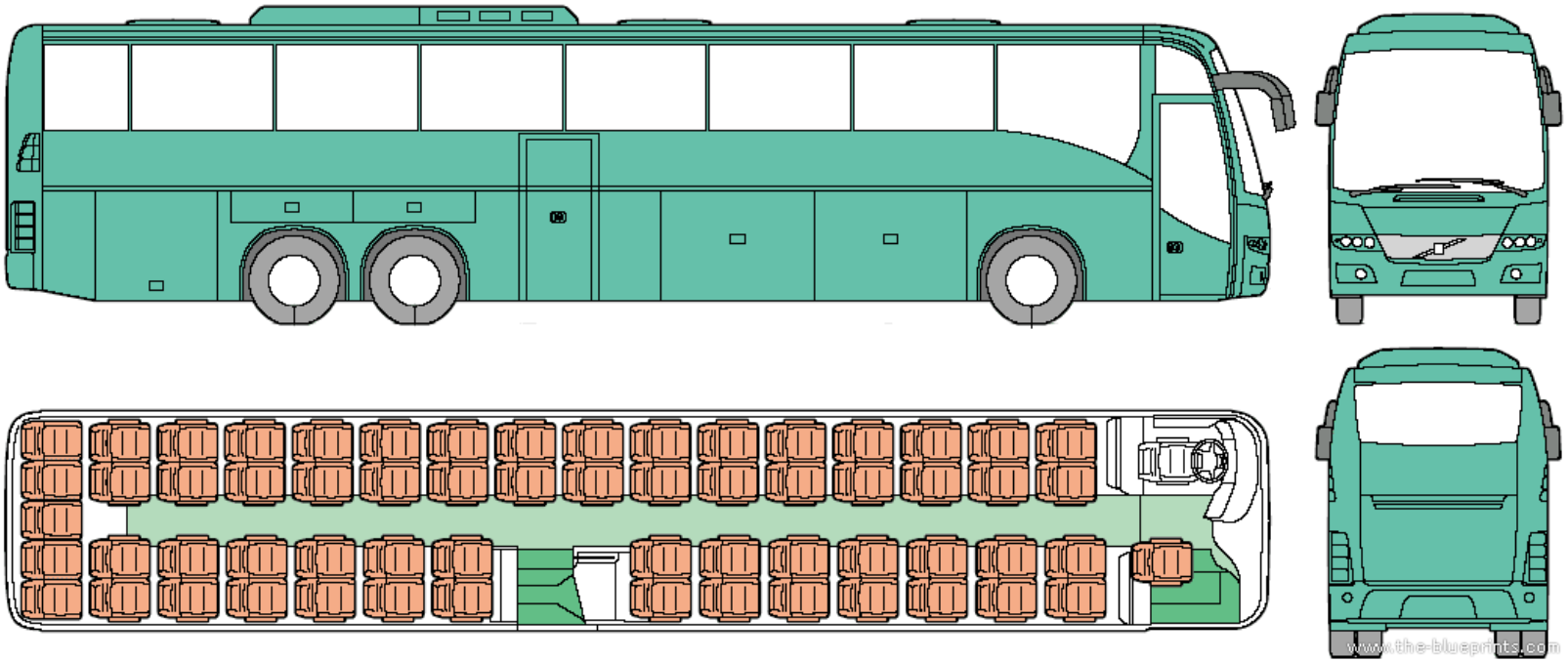
1. Breaking and charging the acumulator
2. Compression of air and use of excess hydraulic energy


0M
Gear Box
Shaft 1
Hybrid
Transmission
1P
Shaft 2
Differential
Output 2
Hydropneumatic
System
Output 1
Output 3
G
2Z1
Pneumatic
circuits

Preliminary results

VOLVO 9700 Bus: 12.3 m, RHD, 4x2, Euro 5

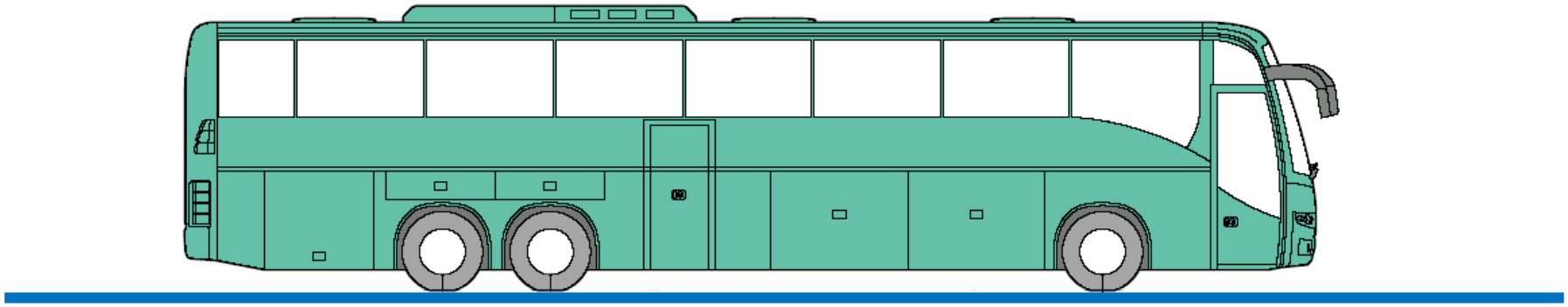
Maximum load: 19 ton
Engine power: 320 kW (420 Hp)



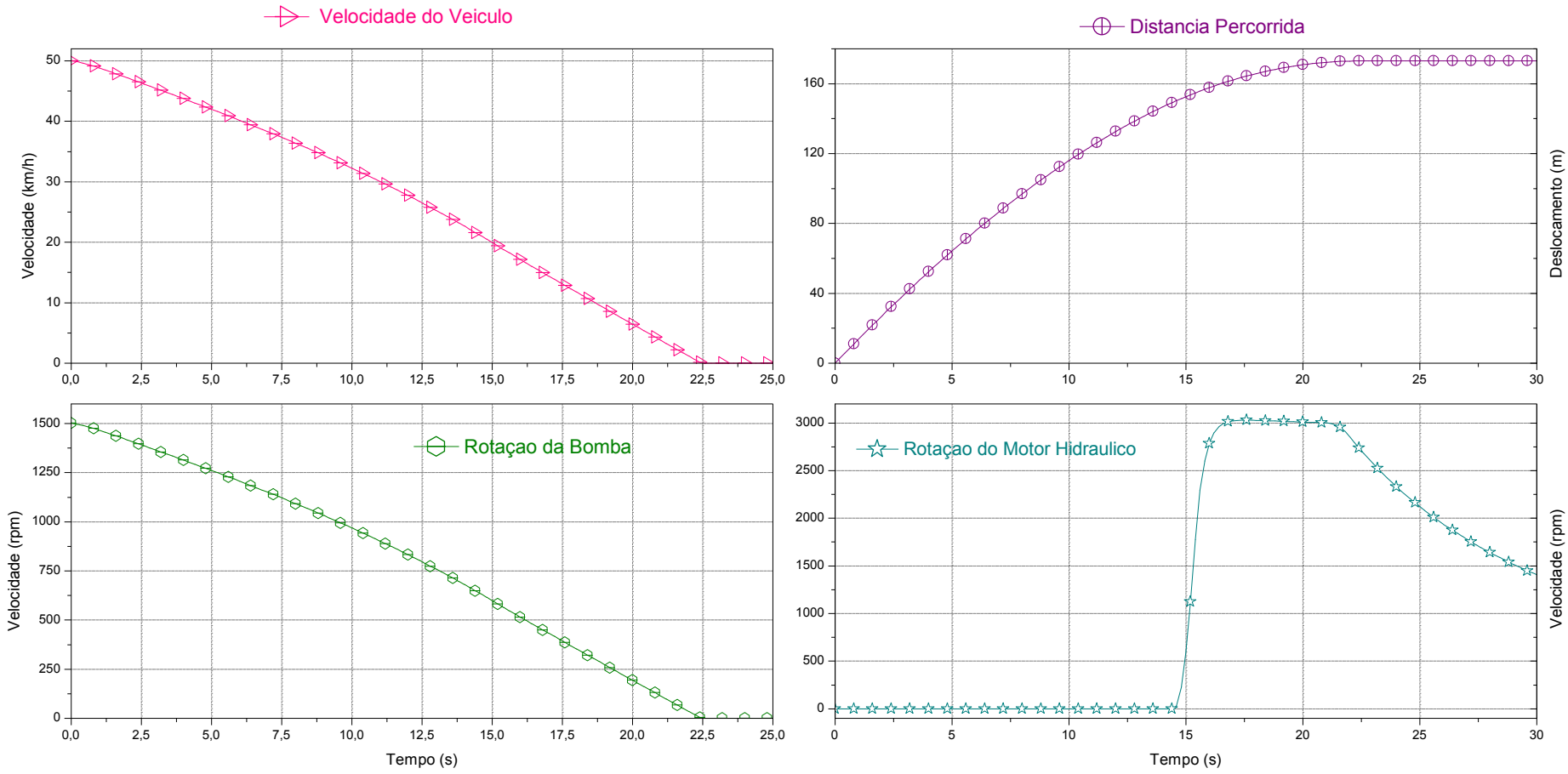
Preliminary results

Variable	Value
Vehicle speed	13.9 m/s (50 km/h)
Road inclination	3º
Pneumatic circuit pressure	0.5 Mpa
Volume of air reservoir	0.1 m^3
Hydraulic pump	180 cm^3/rot
Hydraulics working pressure	35 Mpa
Pre-charge pressure	10 Mpa
Volume of hydraulic accumulator	64 liters

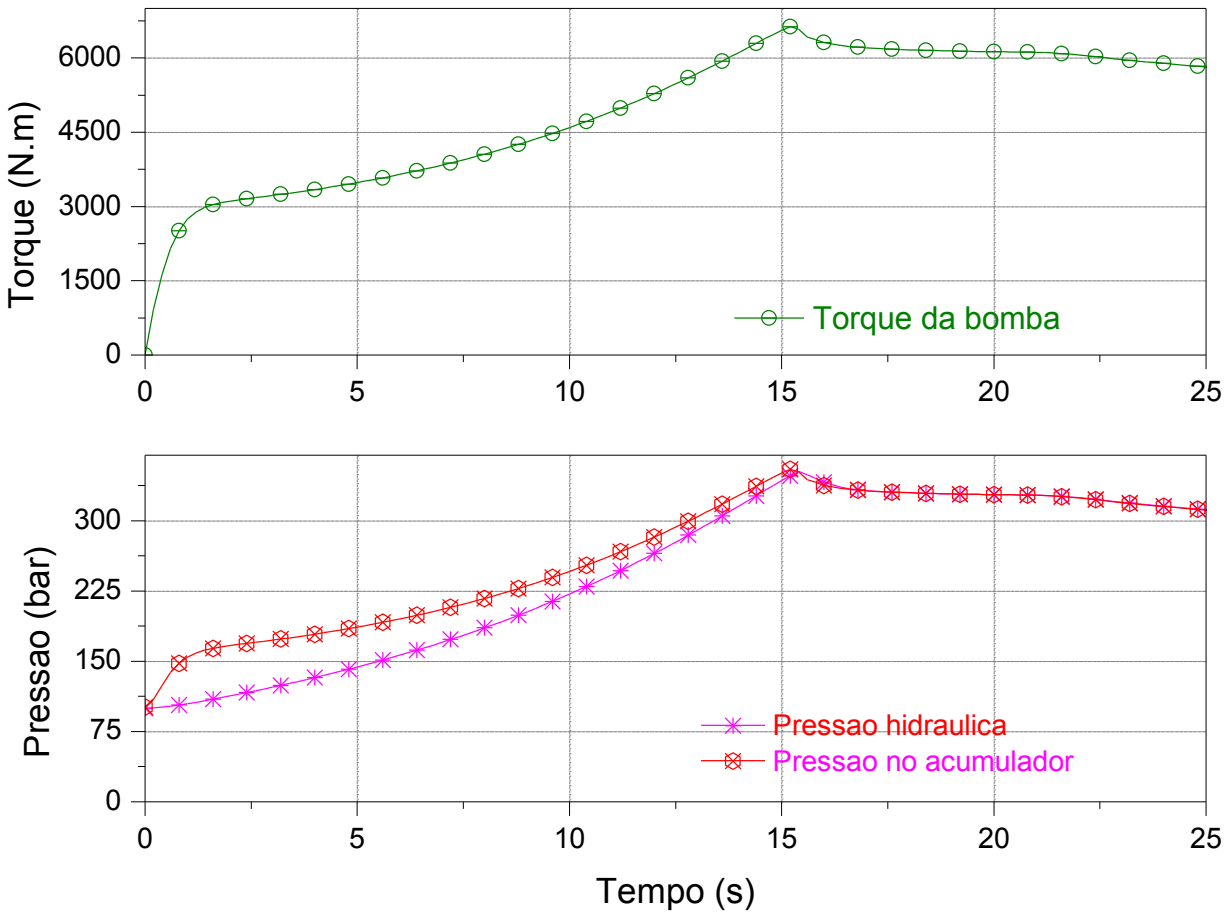
1. Horizontal breaking



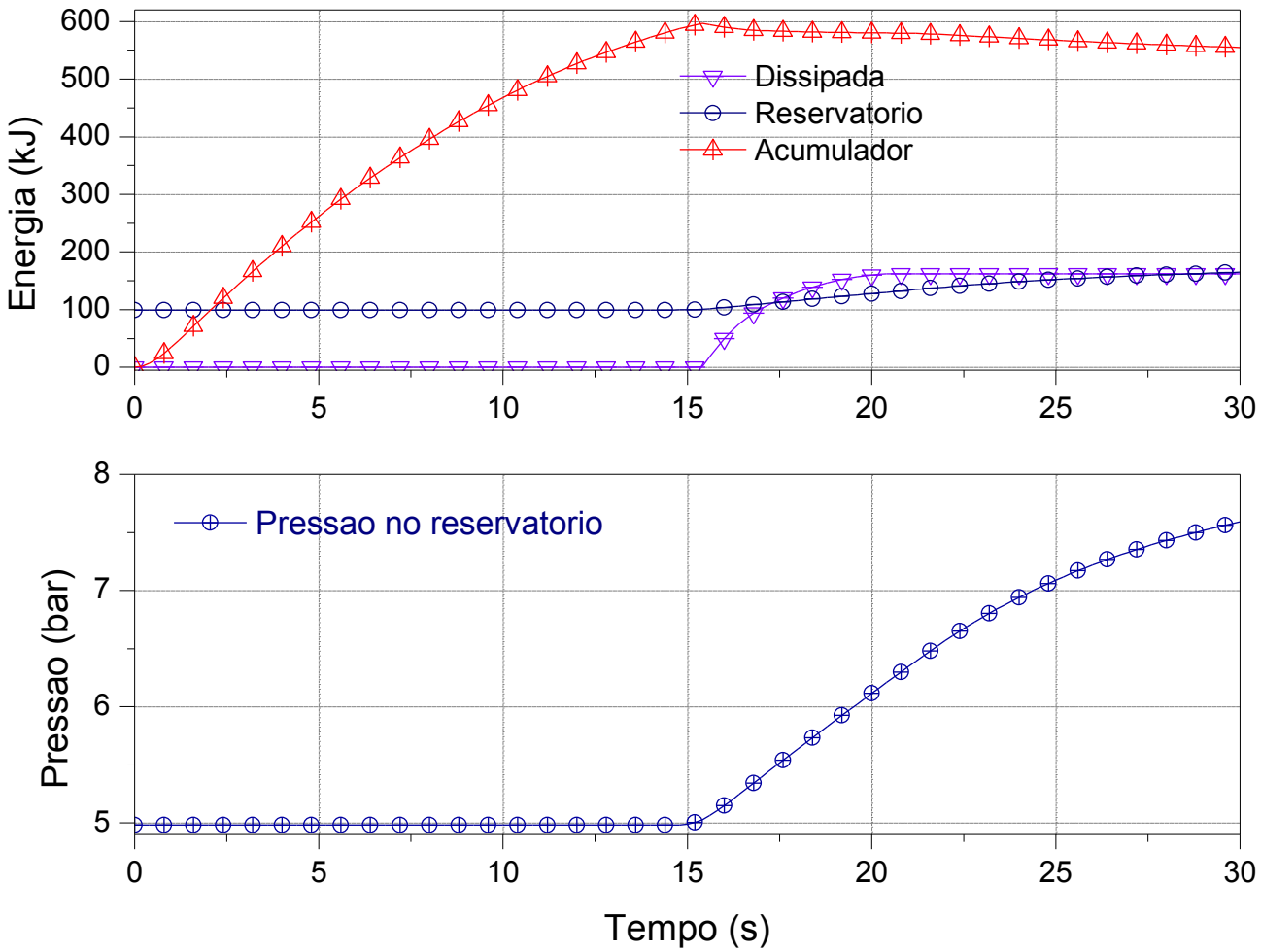
Vehicle speed and distance, Speed of pump and hydraulic motor



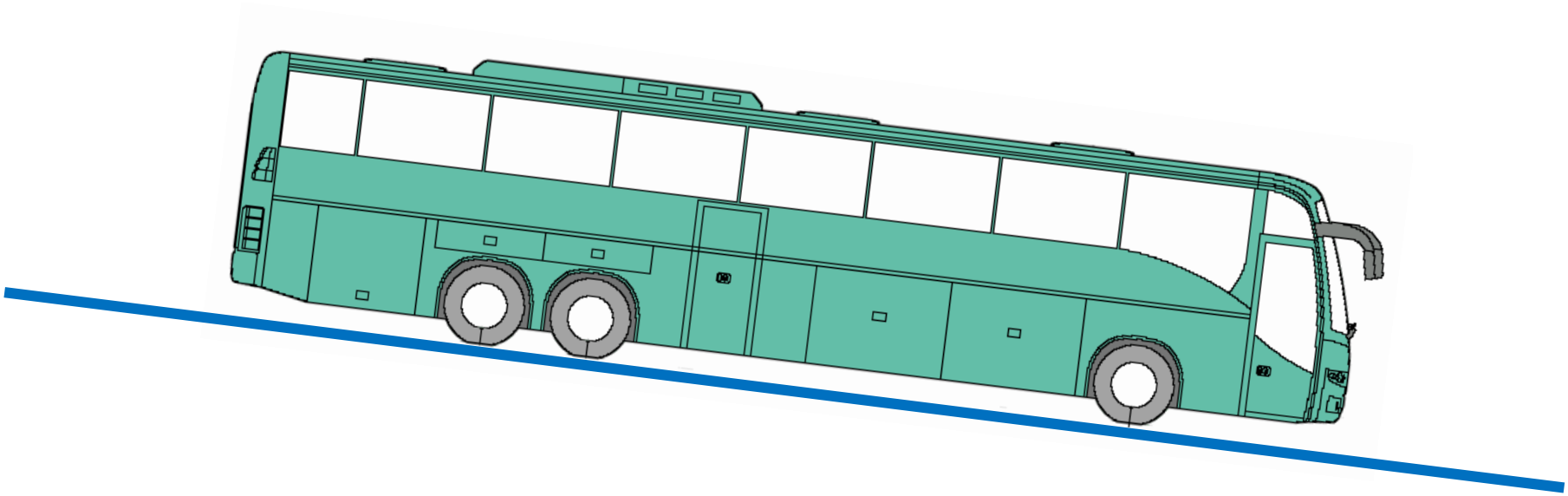
Pump torque,
Pressure in the hydraulic system and accumulator



Energy dissipated and accumulated in the reservoir and accumulator, Pressure in the reservoir



2. Breaking while descending



Vehicle speed and distance, Speed of pump and hydraulic motor

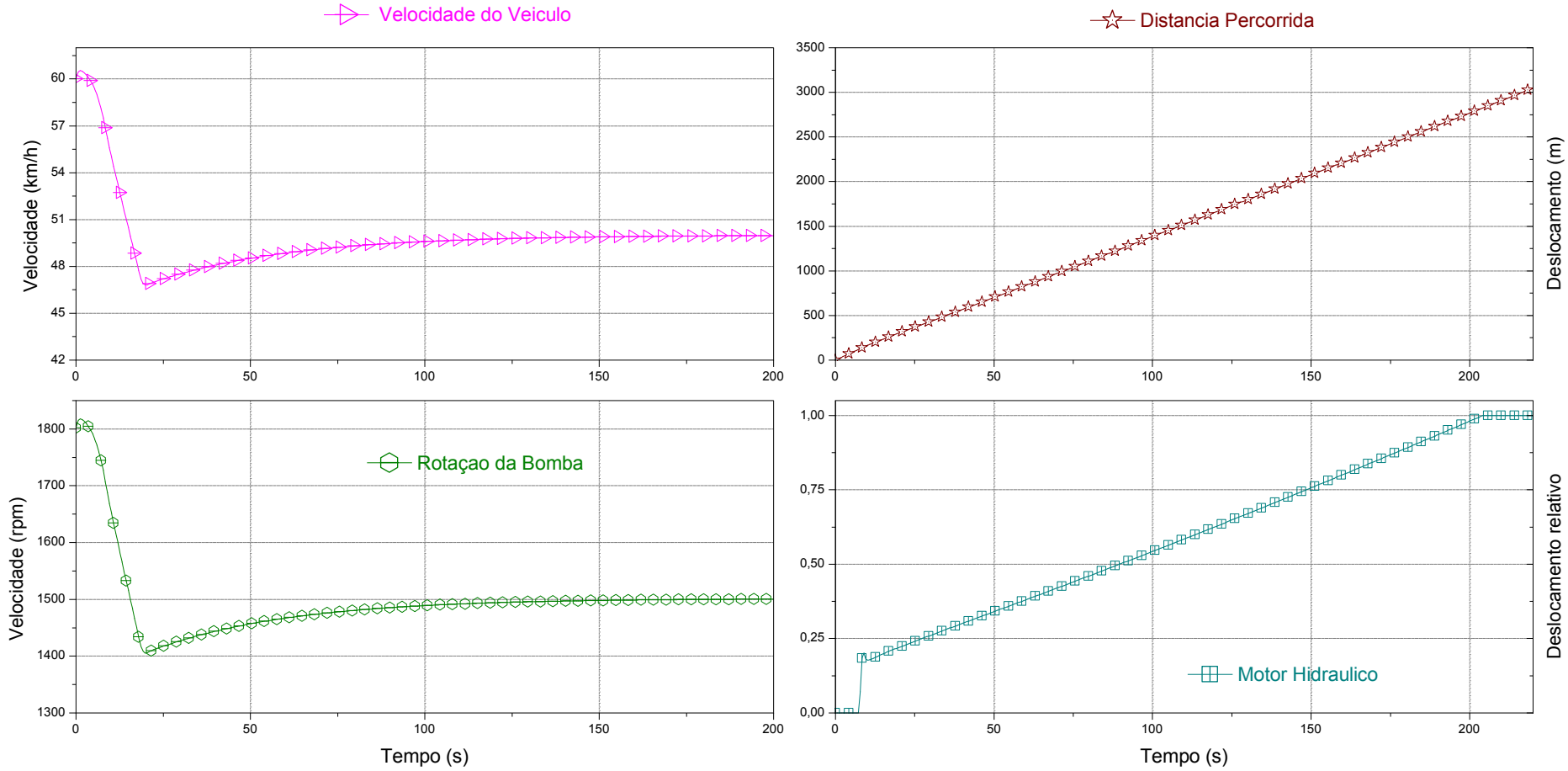
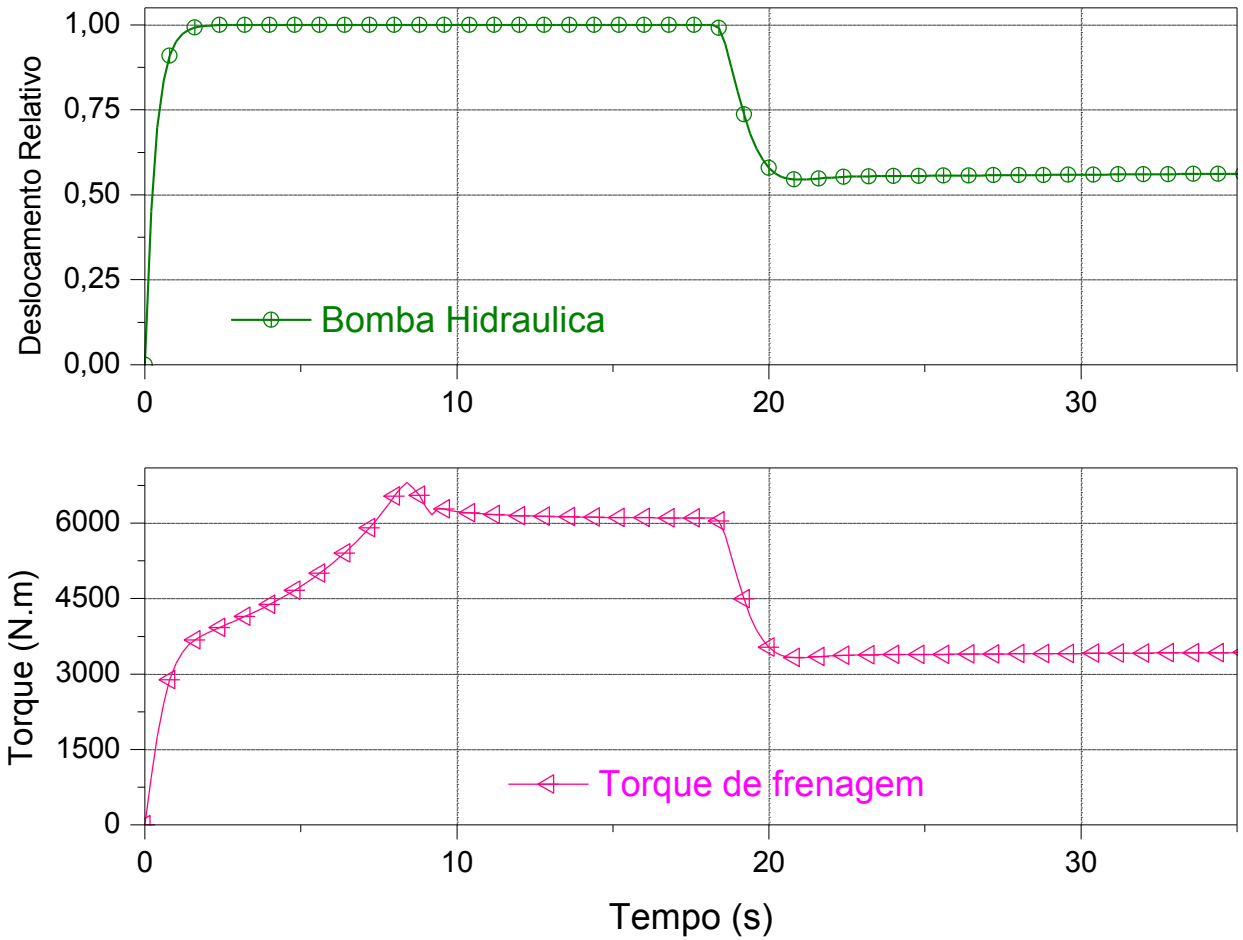
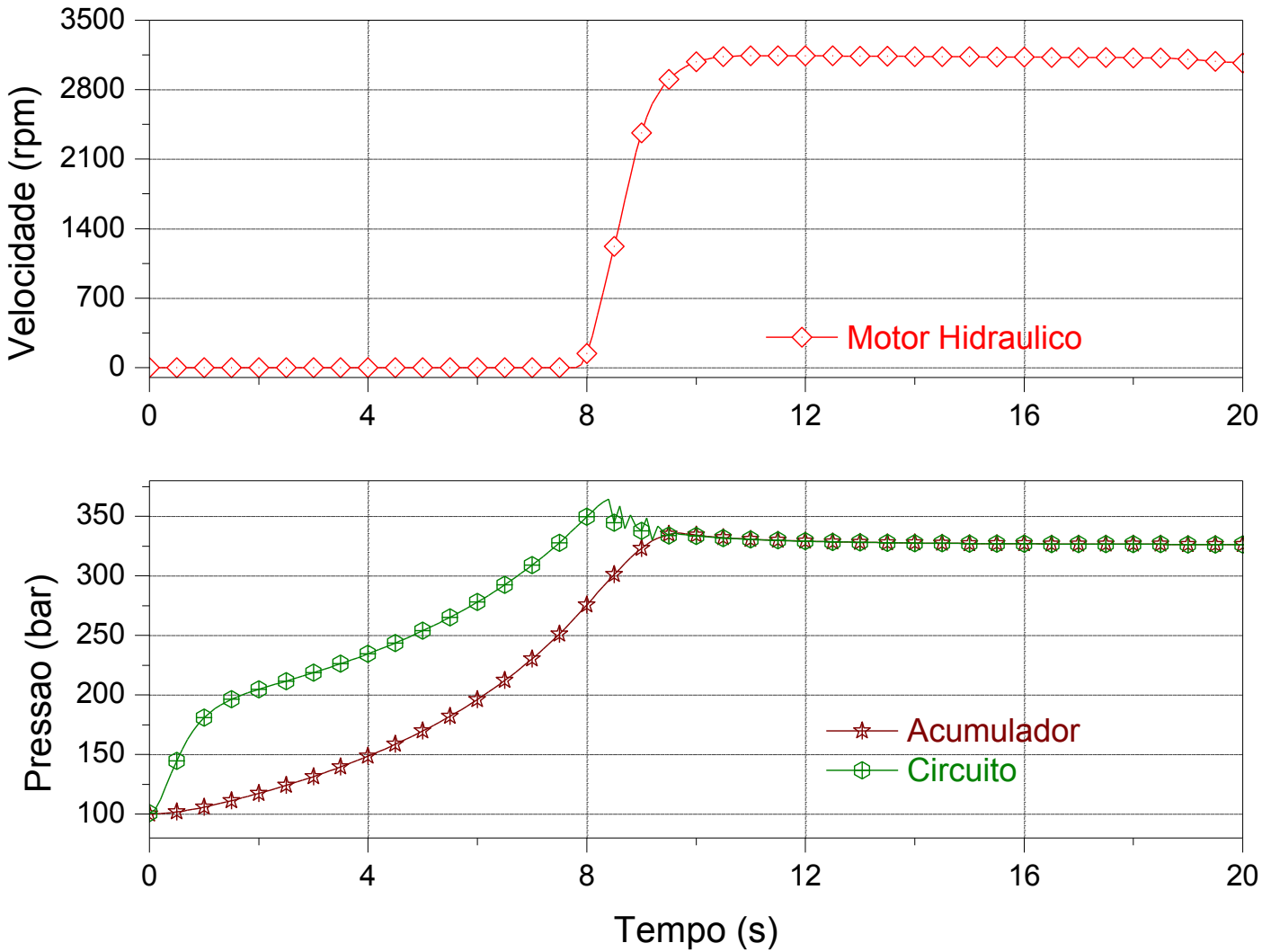


Fig. 46. Resposta do sistema híbrido

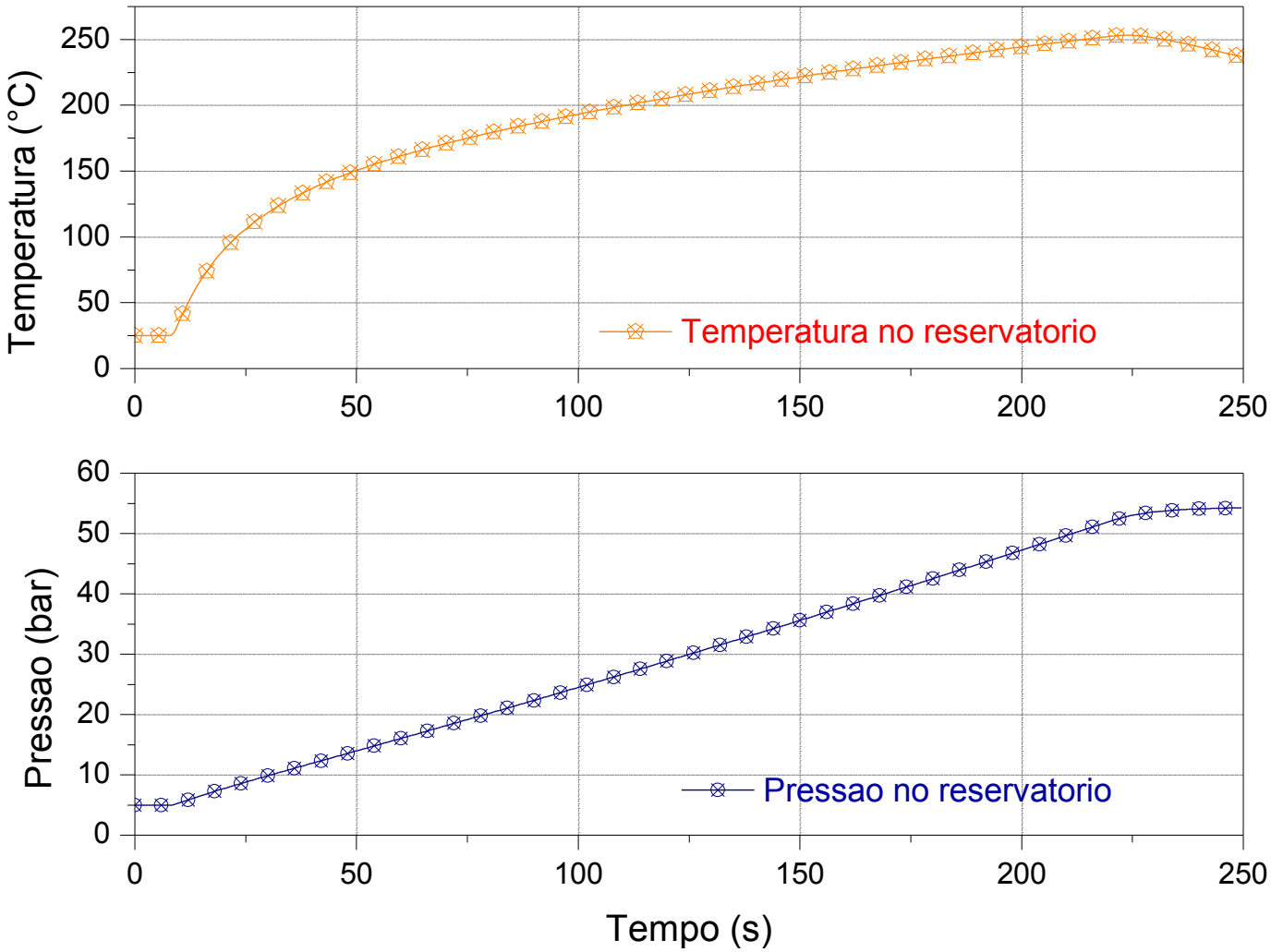
Pump displacement (relative) and torque



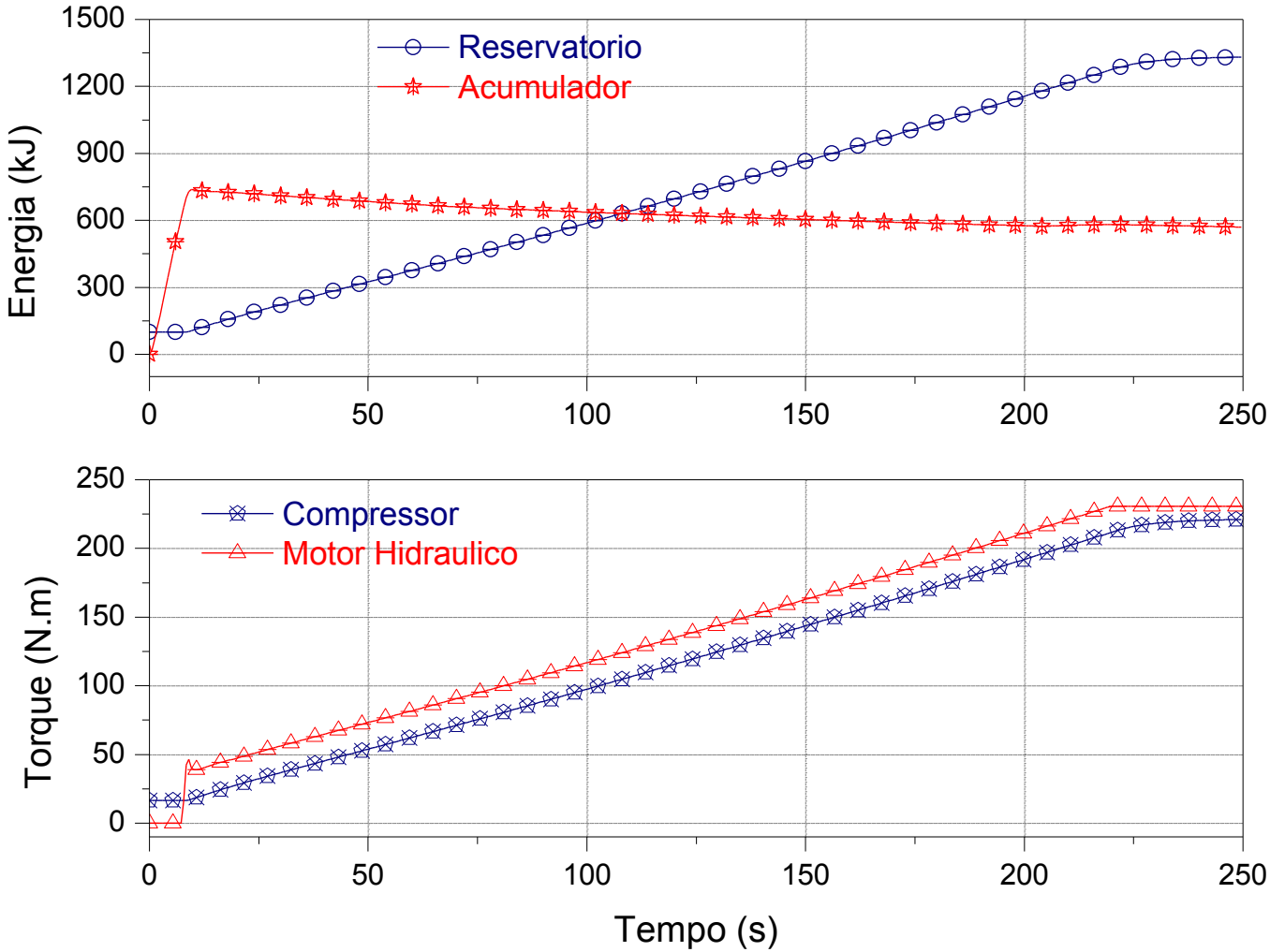
Speed and Pressure in the hydraulic motor



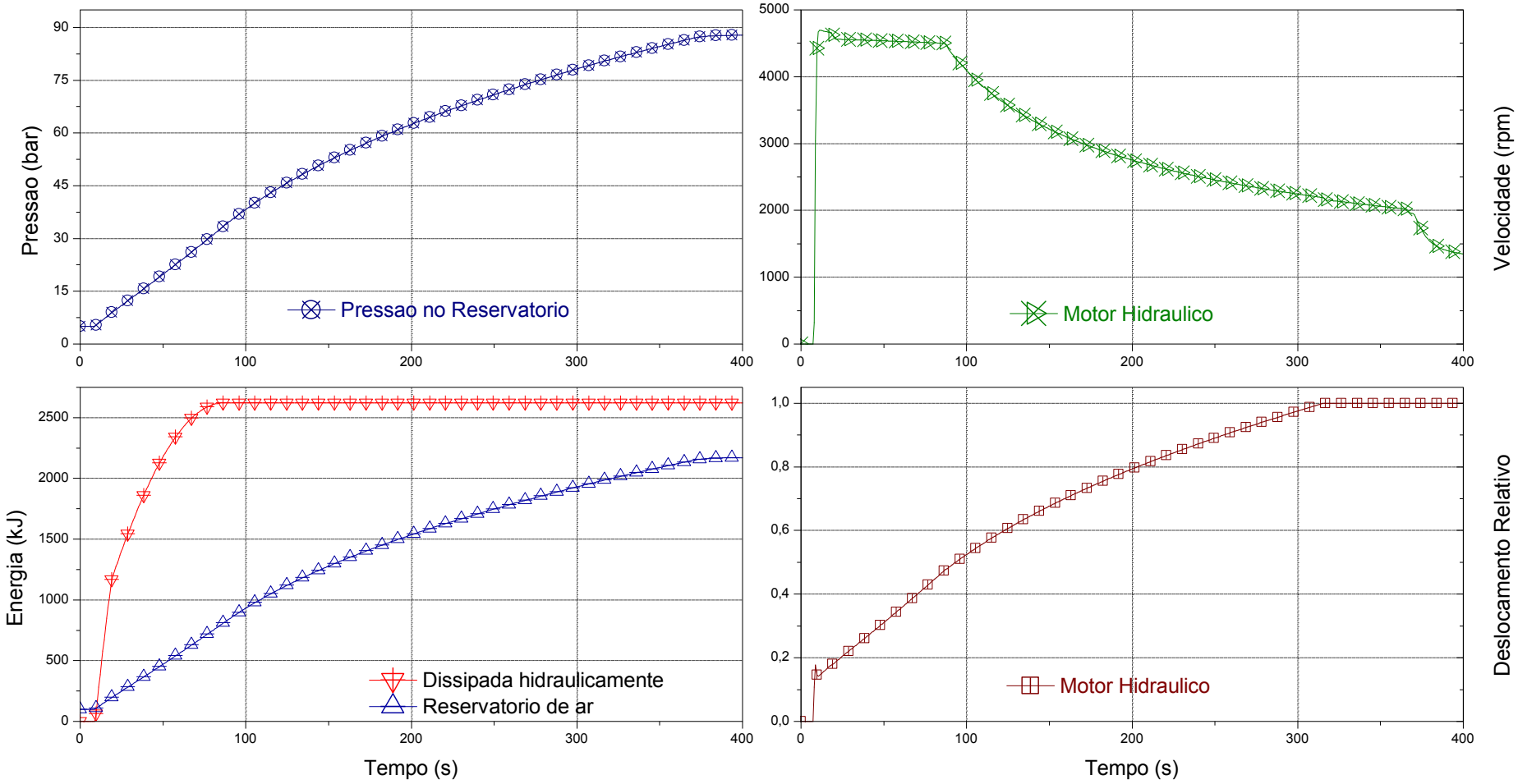
Temperature and Pressure in air reservoir



Energy accumulated in the reservoir and accumulator, Torque in the compressor and pump



Conditions in the hydraulic system for higher energy



Conclusions

- The system proposed stores and uses the stored energy.
- The torque available during breaking is larger than needed.
- The energy stored in the accumulators can be used while the vehicle is moving.

Conclusions

- The hydro-pneumatic system has 3 times more capacity than commercially available systems
- Possible improvements:
  - Increase pressure in the hydraulic system for 42 Mpa
  - Increase compressor capacity
  - Use thermal insulation in the reservoirs
  - Use na electrical generator in parallel with the pump

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LASHiP HYDRAULICS & PNEUMATICS

LABCET Laboratório de Combustão e Engenharia de Sistemas Térmicos

VOLVO