

# REDUCTION OF PARASITIC LOSSES IN HEAVY-DUTY DIESEL ENGINE COOLING SYSTEMS

Nik Staunton, Ryan Maughan  
Comesys Europe Ltd.

Kevin Jackson  
EMP Inc.

## Overview of this presentation

- A review of traditional cooling systems
- Drawbacks of using a standard system
- What is advanced thermal management?
- How does this equate to a reduction in parasitic loss? (individual system components and system control)
- Results from EMP
- Conclusion
- References

# Overview

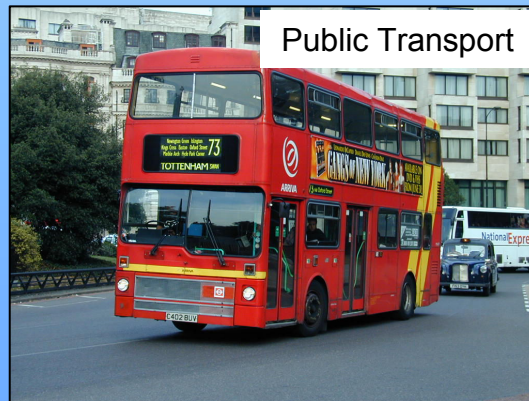
High thermal loads  
Auxiliary systems  
Low speed operation



High thermal loads  
Low speed operation  
Harsh environment



Variable load  
Large transient load  
High + low speed

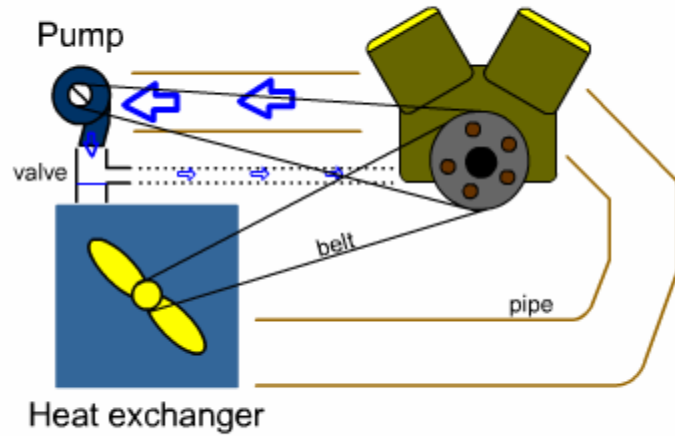


Overnight idle  
High speed operation  
Variable load

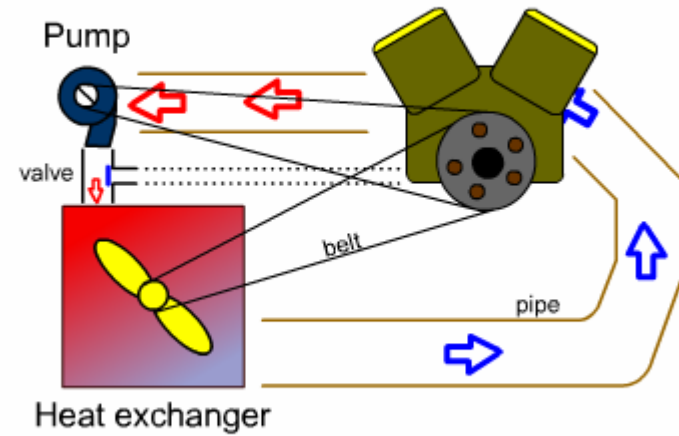


# The Standard Cooling System

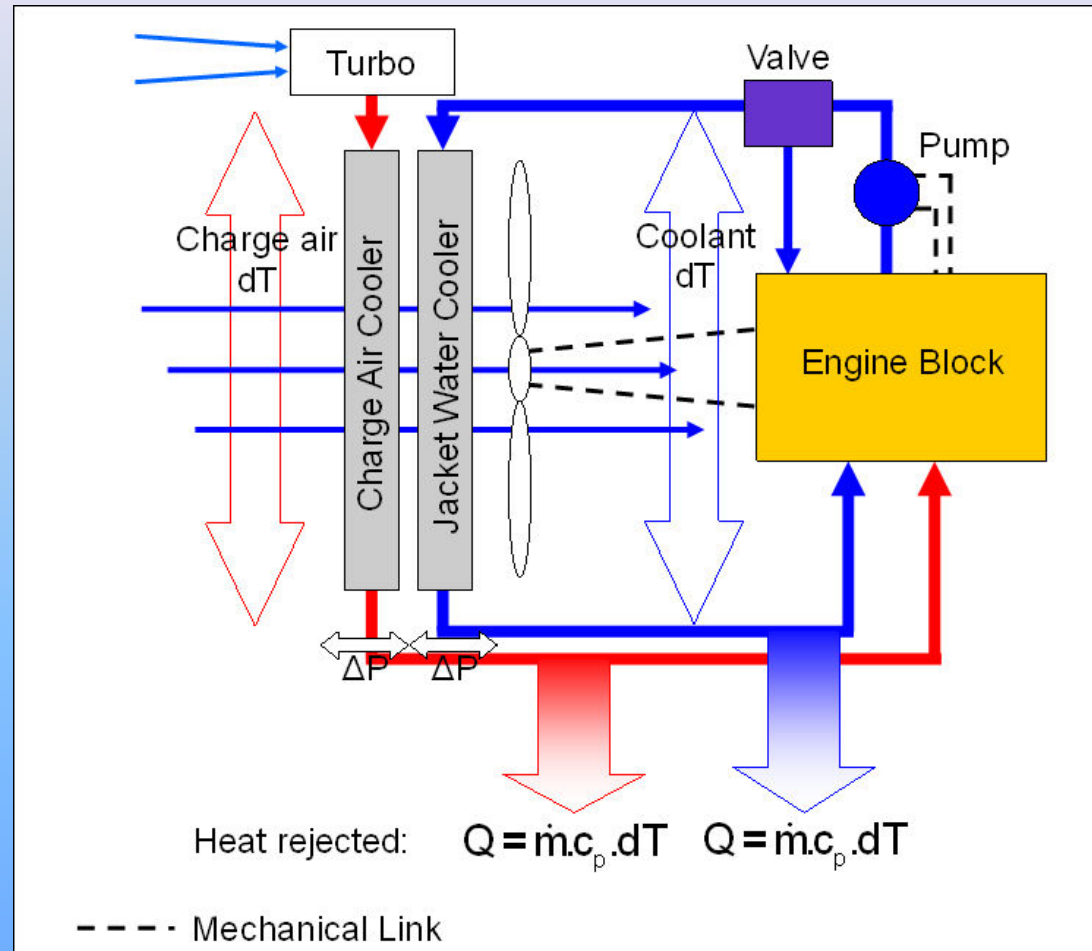
COLD



HOT



# The Standard Cooling System



# The Standard Cooling System

There are two main disadvantages in the standard system

- Always on
- Lack of control

Problems associated with always on operation

- Increased warm-up time
- Overcooling during low load / high speed operation
- Under-cooling during high load / low speed operation
- Power is consumed unnecessarily (Fan, pumps)
- Transient vehicle performance – inertia of fan + pump must be overcome

### **Problems associated with lack of control**

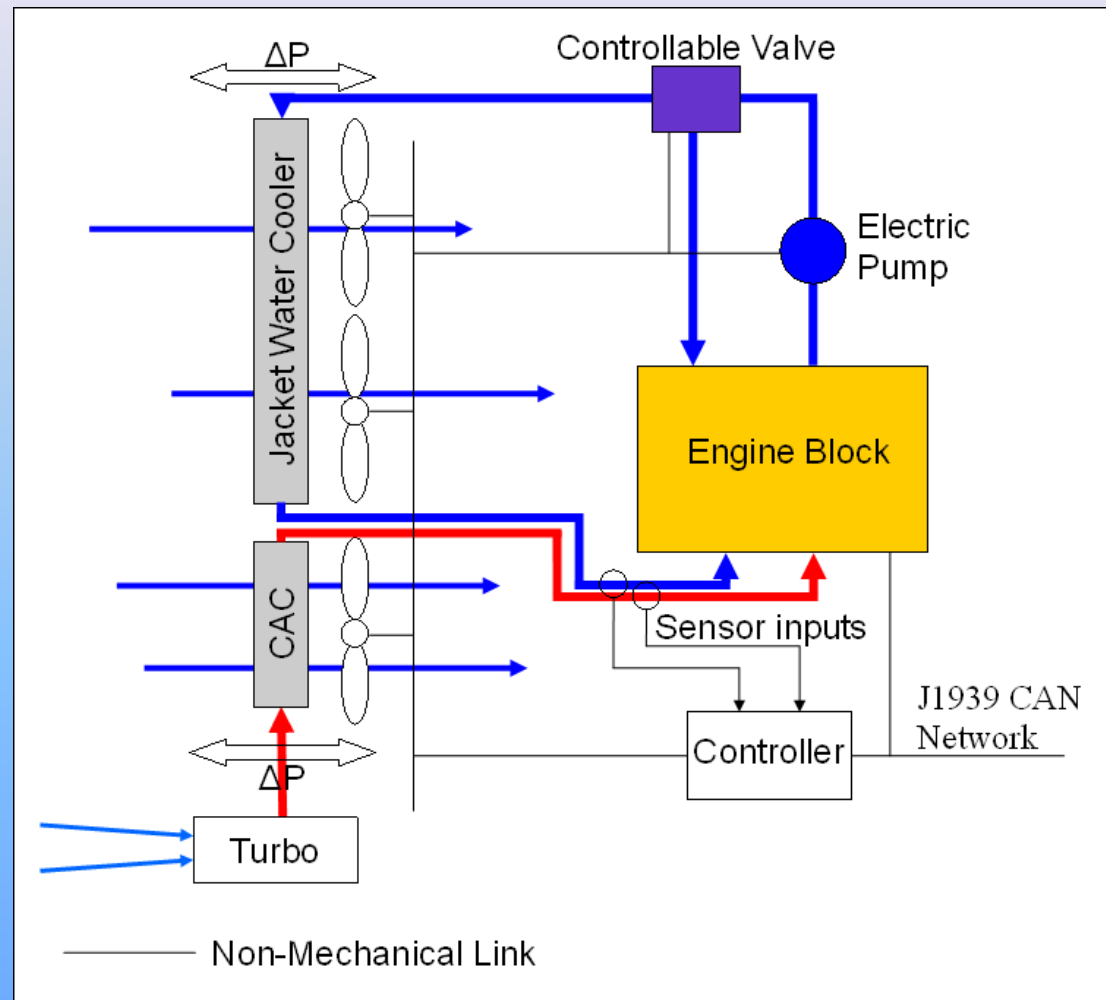
- Increased warm-up time
- Hysteresis effect in bypass valve operation
- Large fluctuations in temperature due to hysteresis
- Lowered maximum operating temperature
- Cooling system performance is a function of engine speed rather than optimum operating temperature
- Cooling system design is driven by worse case performance – adequate airflow at low engine speed, adequate coolant flow at low engine speed

## Other drawbacks

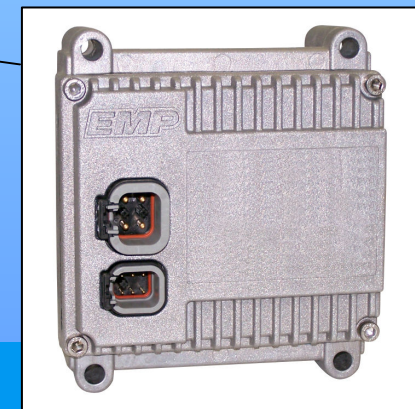
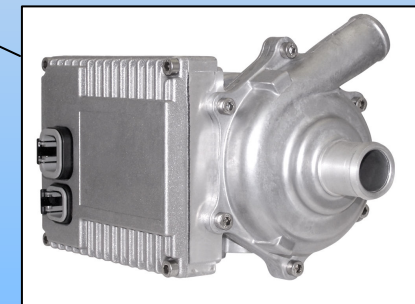
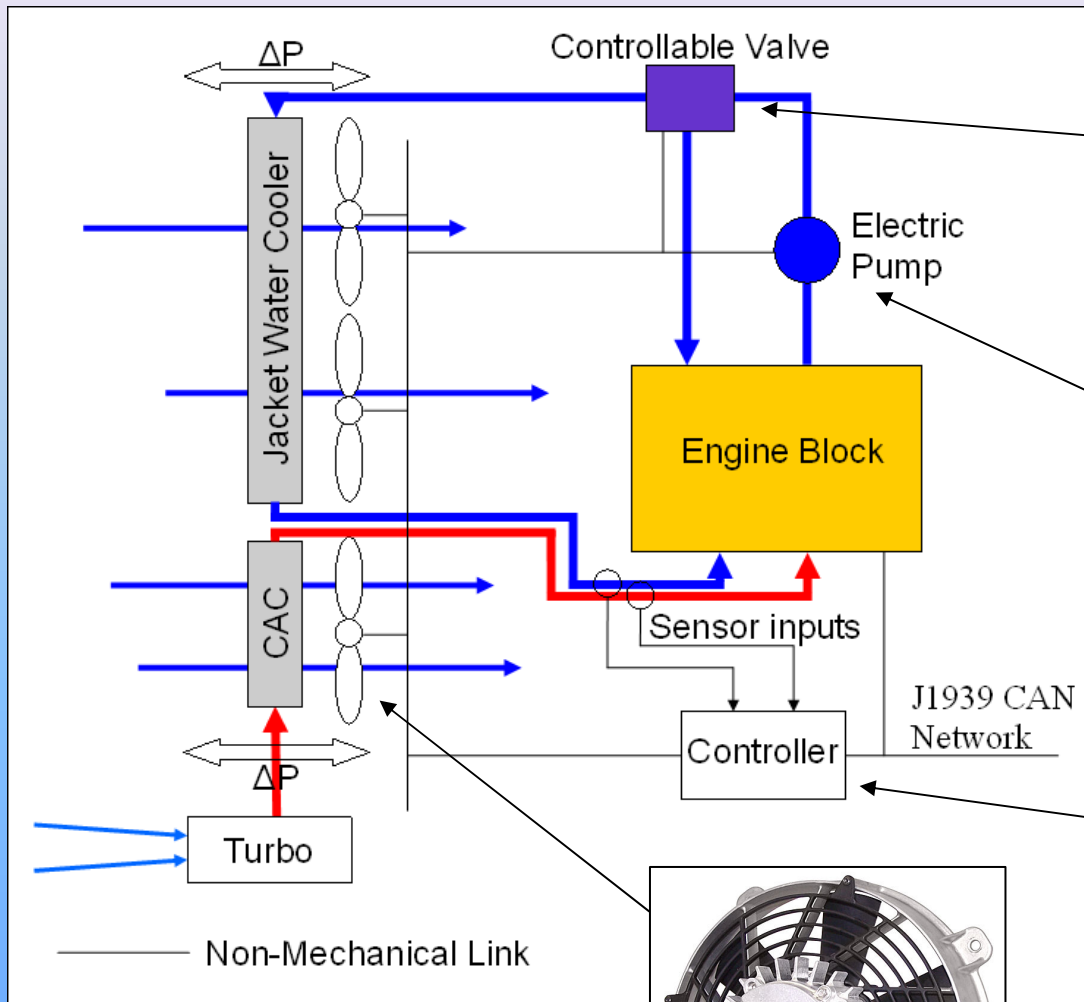
- Large fan is inefficient
- System layout is limited
- Sandwiched heat exchanger arrangement increases the pressure drop to achieve the required cooling air flow.
- The efficiency of the second heat exchanger is reduced due to the cooling air being raised above ambient by the first
- Fans and pumps are designed to meet peak efficiency on a high restriction curve due to sandwiched heat exchanger arrangement



# The hybridised cooling system



# The hybridised cooling system



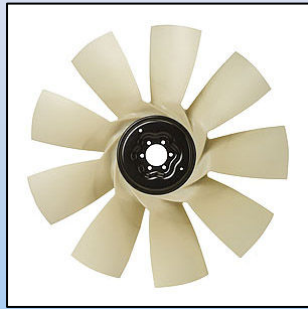
## The hybridised cooling system

### Reasons for moving to a more electric cooling system

- Regulations (Euro IV, Euro V). Removing parasitic loading can help meet these standards
- Full system control
- Heat exchanger size can be reduced
- Less restriction imposed by heat exchangers and valve
- Fan and pump power consumption can be reduced
- Engine temperature can be raised to increase combustion efficiency, reduce friction and increase heat rejection
- Oil temperature can be raised to reduce friction and engine wear
- EGR cooling, oil, and transmission cooling can be handled independently
- A systems approach allows all components to run at their optimum temperature

## The hybridised cooling system - FAN

### Benefits of smaller, electric fans



- Smaller fans running at higher speed consume less power and can be switched off completely
- No belt losses
- BLDC drives are very efficient (95% +)
- Fan speed can be a function of any system variable we choose – coolant temp, IMT, valve bridge temp etc.
- Independent control of charge air temperature, coolant temperature, oil temperature
- Fans are reversible for debris removal

# The hybridised cooling system - FAN

## Fan Laws

Can either  
change the size  
or the speed

$$\longrightarrow \text{Capacity} = \left( \frac{\text{SizeA}}{\text{SizeB}} \right)^3 \times \left( \frac{\text{SpeedA}}{\text{SpeedB}} \right)$$

Reason for using large fan

Pressure is fixed  
for a given heat  
exchanger and  
vehicle  
resistance

$$\longrightarrow \text{Capacity} = \left( \frac{\text{SizeA}}{\text{SizeB}} \right)^2 \times \left( \frac{\text{PressureA}}{\text{PressureB}} \right)$$

Fixed system restriction

Fan power is a  
function of  
speed and size

$$\longrightarrow \text{Power} = \left( \frac{\text{SizeA}}{\text{SizeB}} \right)^5 \times \left( \frac{\text{SpeedA}}{\text{SpeedB}} \right)^3$$

# The hybridised cooling system - FAN

## Simple proof of concept

Initial Size = 1

Initial Speed = 1

Capacity =  $1 \times 1 = 1$

Power =  $1 \times 1 = 1$

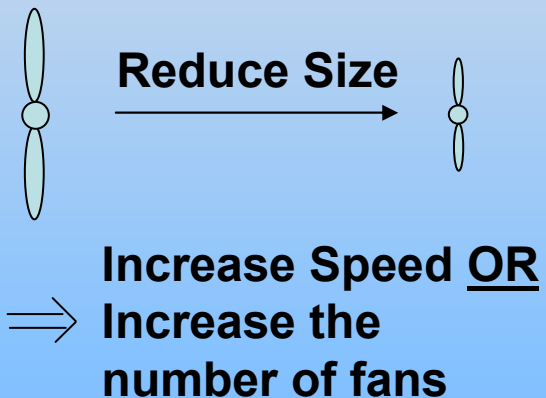
Reduce the fan size to  $\frac{1}{2}$

⇒ Need to increase fan speed or use more fans

$$\text{Capacity} = 1 = \left(\frac{1}{0.5}\right)^3 \times (\text{New Speed Ratio})$$

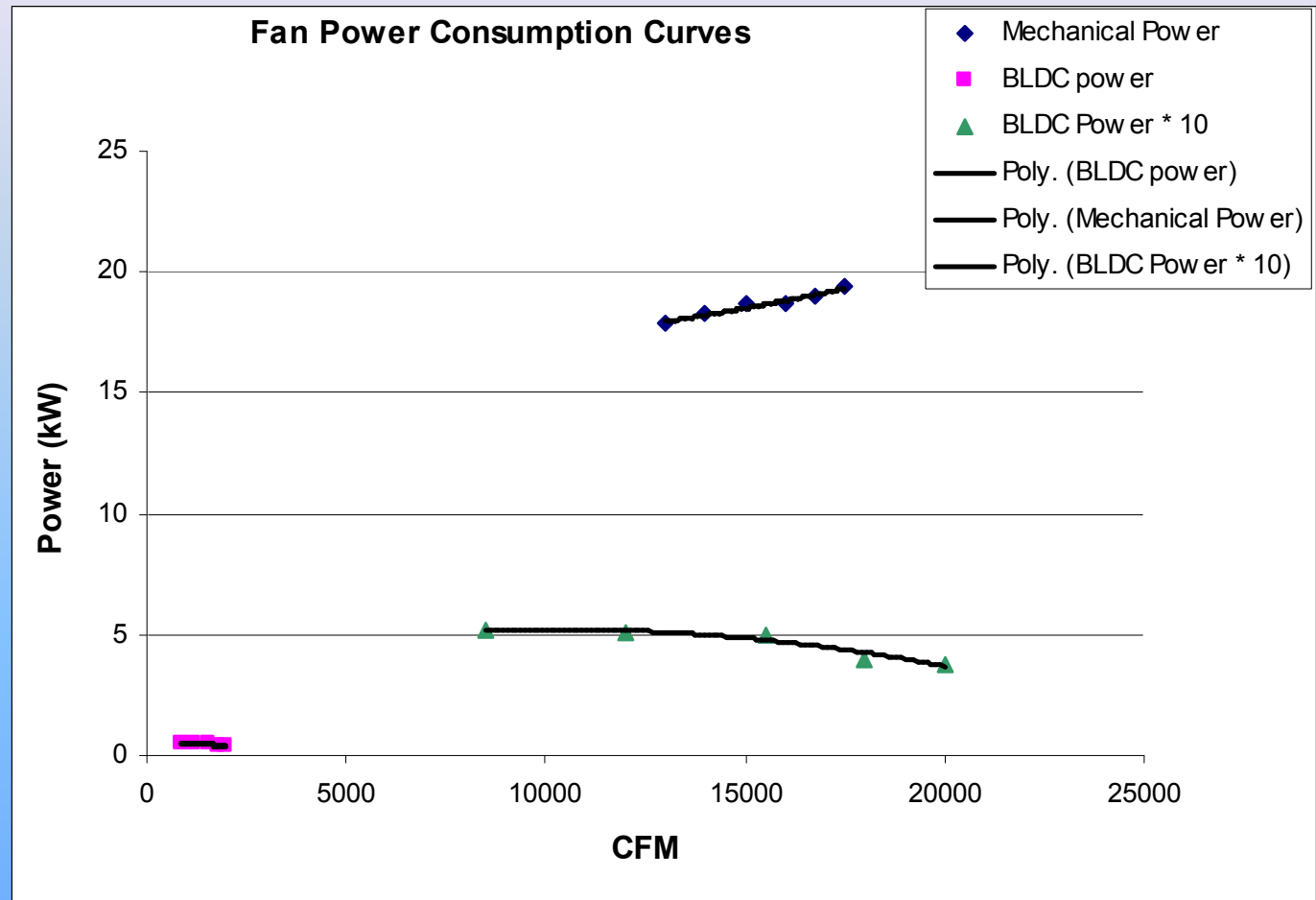
New Speed Ratio = 0.125

$$\text{New Power Ratio} = \left(\frac{1}{0.5}\right)^5 \times \left(\frac{1}{8}\right)^3 = 0.06$$



# The hybridised cooling system - FAN

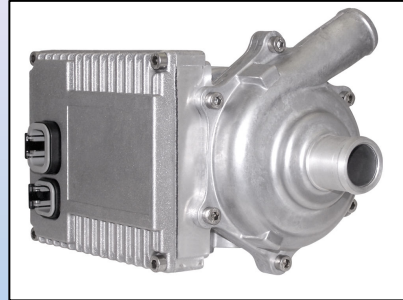
Comparable flow rate performance is achieved using multiple BLDC fans with a large reduction in energy consumption



Maximum power consumption vs. flow rate

## The hybridised cooling system - PUMP

### Pump



- A standard coolant pump is designed to meet flow requirements at maximum engine load
- For direct driven pumps, it is estimated that the correct coolant flow is delivered only 5% of the time (EMP)
- At low engine speeds with high loads, e.g. construction equipment, coolant flow can be low
- At high engine speeds with low loads, e.g. an empty bus on a highway, coolant flow can be excessively high, consuming power and fuel unnecessarily



## The hybridised cooling system - PUMP

### Benefits of an electric coolant pump

- Operation is independent of engine speed
- No belt losses
- BLDC drives are very efficient
- Pumping speed can be a function of any system variable we choose – coolant temp, IMT, valve bridge temp etc.
- Minimum coolant flow is ensured at all times
- Heat exchanger radiation can be maximised before engaging cooling fans – the largest power consumer

## The hybridised cooling system - PUMP

Target is to achieve heat rejection without resorting to forced convection

A large aluminium radiator gives us the means to do this

Radiative heat transfer is given by:

$$q = \varepsilon \cdot \sigma \cdot T^4 \cdot A$$

$q$  = heat transfer

$\varepsilon$  = emissivity

$\sigma$  = Stefan - Boltzmann constant

$T$  = Absolute Temperature

$A$  = radiator surface area

We can exploit the fact that heat transfer depends on the 4<sup>th</sup> power of absolute temperature

## The hybridised cooling system – VALVE

### Electronic Thermostat Valve



- A wax based valve opens and closes as a function of temperature
- Hysteresis in this process allows for large fluctuations in coolant temperature
- High restriction in the valve means that pumping losses are increased
- Warm-up time of the vehicle depends heavily on the valve

## The hybridised cooling system – VALVE

### Benefits of an electronic thermostat valve

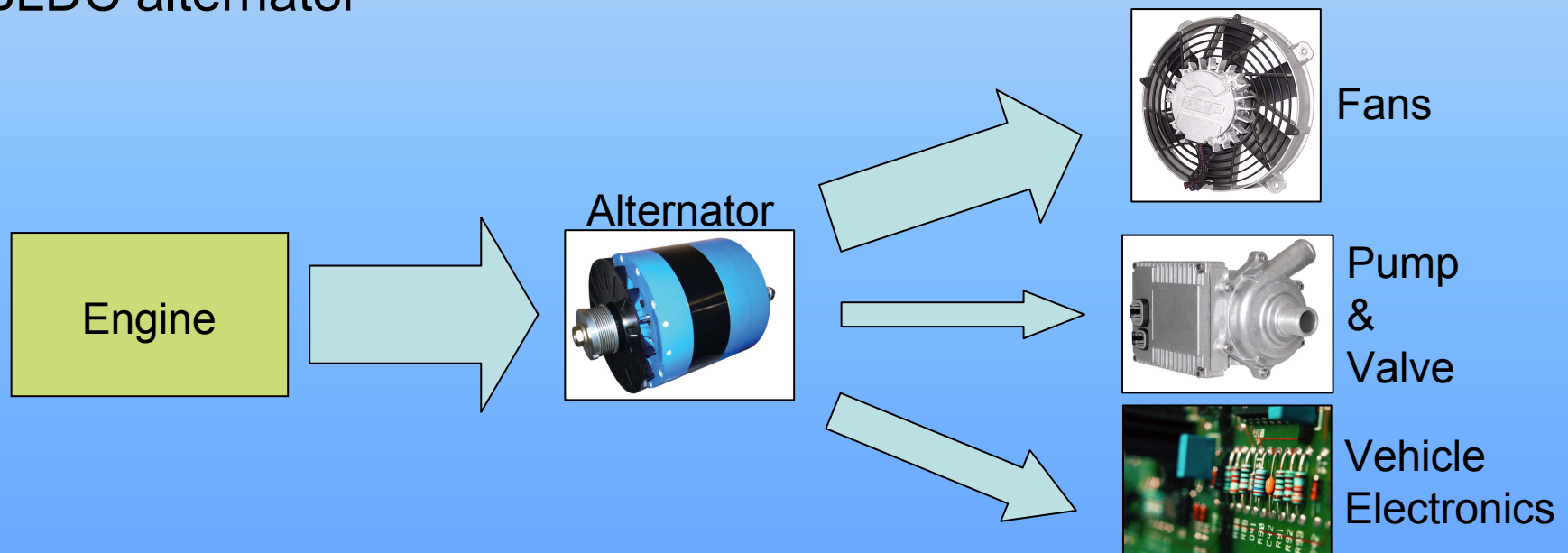
- The flow of coolant to the heat exchanger can be a function of any system variable
- A lower restriction means that pumping losses are lower and the coolant pump consumes less power
- PID or other control strategies can be employed to help keep coolant temperature to within +/- 2% of the set temperature
- Reductions in fuel consumption of 2% – 5%, 20% less CO and 10% less HC emissions have been proven (Valeo)

## The hybridised cooling system – ELECTRICAL SYSTEM

A fully electrified cooling system can draw up to 330 Amps on a 24V electrical system

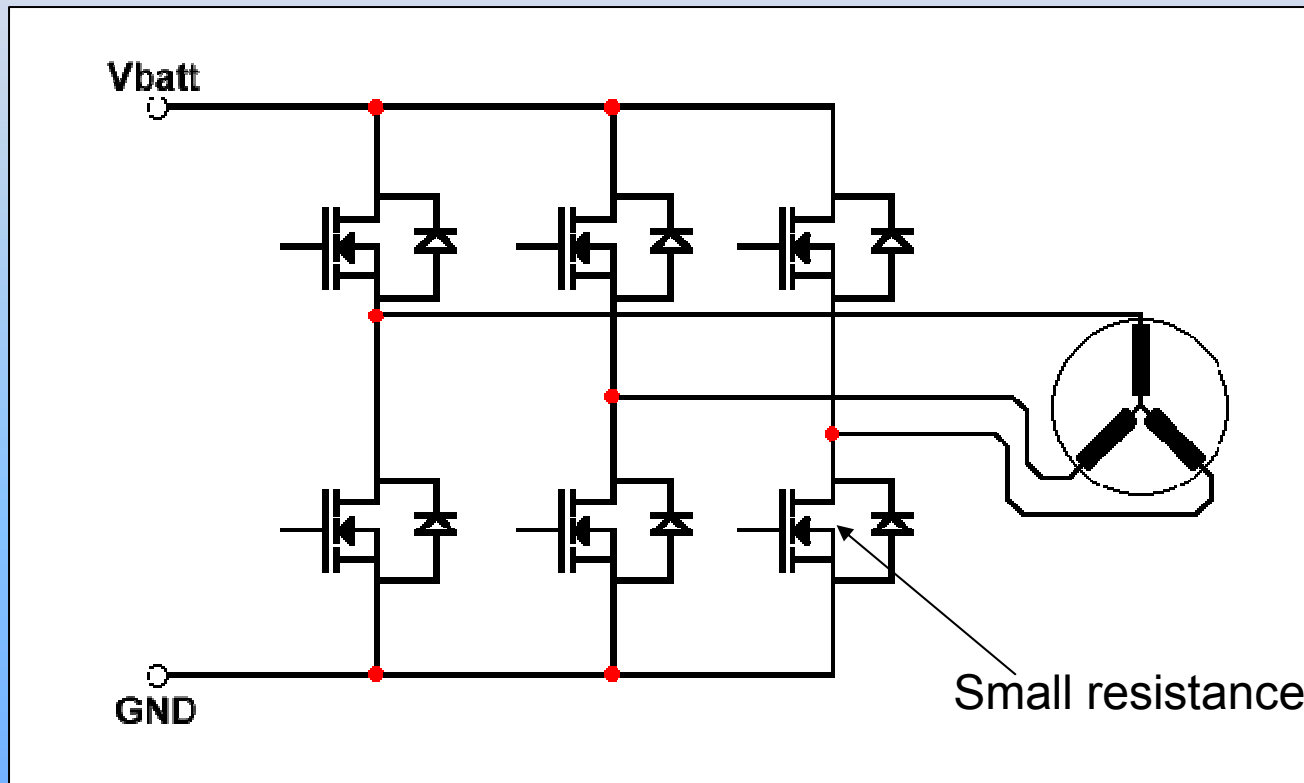
Most standard electrical systems cannot satisfy this alone, not including other vehicle electrical systems

A short term solution to this is to employ a very high efficiency, BLDC alternator



## The hybridised cooling system – ELECTRICAL SYSTEM

BLDC drive efficiency can be improved by moving to a higher voltage electrical system



Efficiency related directly to operating voltage

Micro-hybrid systems enable minimisation of  $i^2R$  losses

## System control

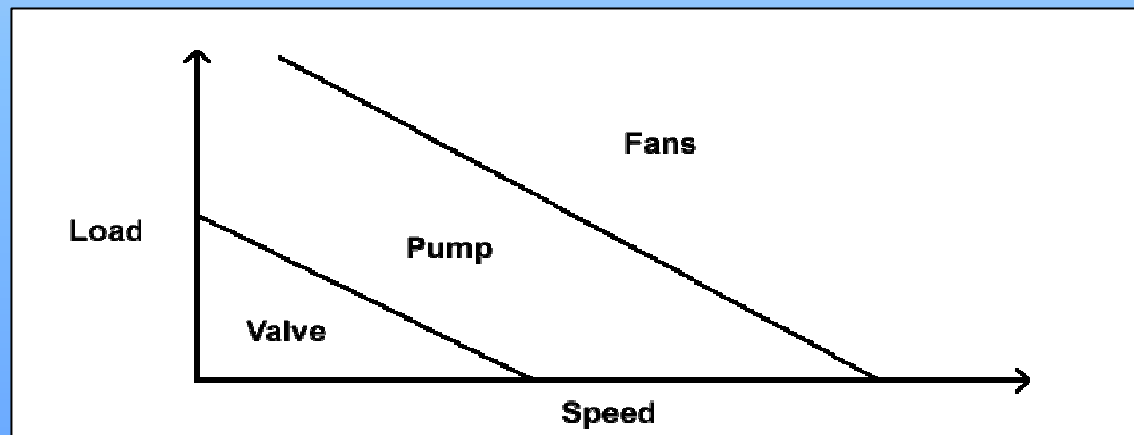
So far, I have emphasised the benefits of simply replacing components in the cooling system – this is only the first step

We do not want to emulate the standard cooling system behaviour

Correct control is crucial to power consumption reduction

Ideally, the engine temperature should be maintained using the low power consuming components – high power consumers are only employed as a last resort

Control algorithms used in conjunction with an accurate vehicle model can enable feed forward control that will enable temperature transients to be reduced further



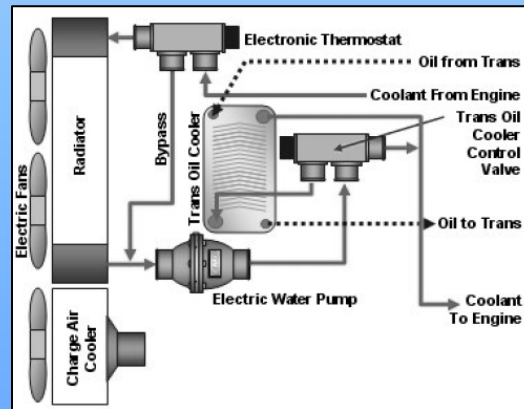
## EMP's Results

Volvo VN 64T – (electric fans, pump, valve @ 42V) Up to 5% fuel consumption reduction

Ford Excursion – (electric fans, pumps, valve, water cooled CAC) 85% parasitic load reduction, 8.9% fuel consumption reduction, up to 10% in steady state

Stewart and Stevenson M1084A1 Cargo Truck – Between 5% and 20% fuel consumption reduction during steady state operation

New Flyer D40LF – (electric fans, coolant pump, valve) 80 installations. 10% reduction in fuel consumption. Average cooling system power consumption of 221W

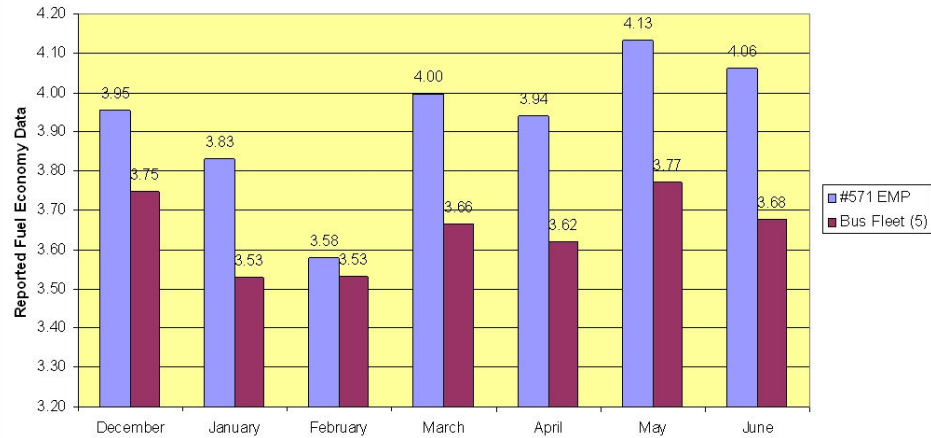


*Advanced cooling system installed by EMP Inc.*

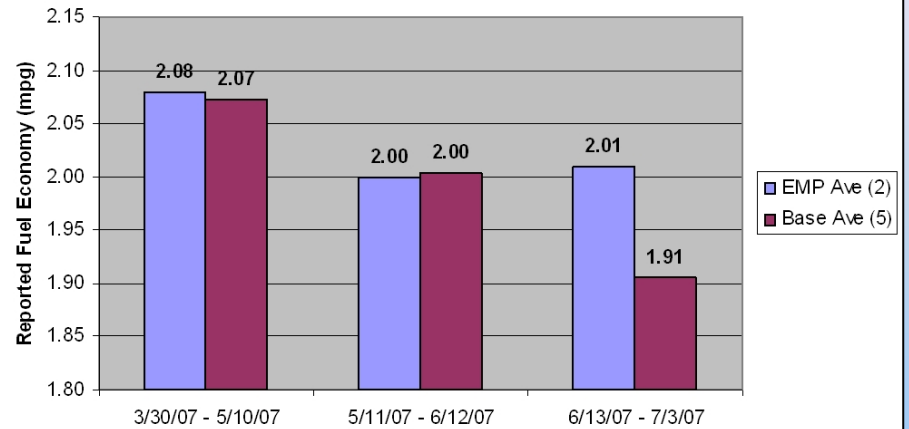


# EMP's Results

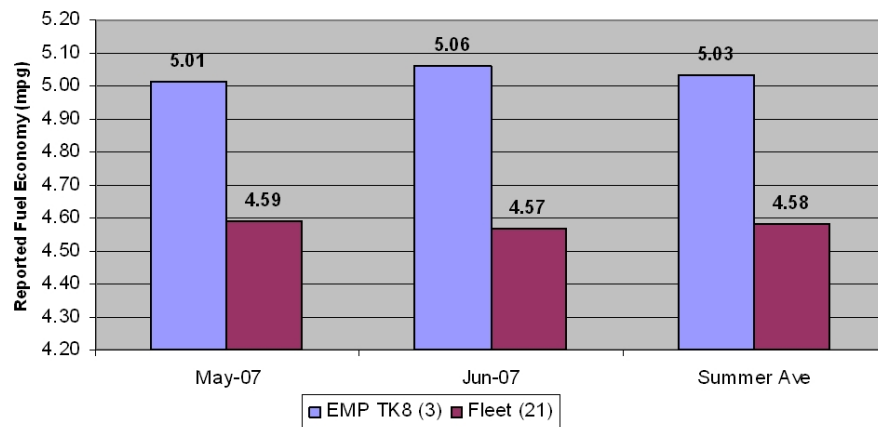
### CATA Bus Comparison



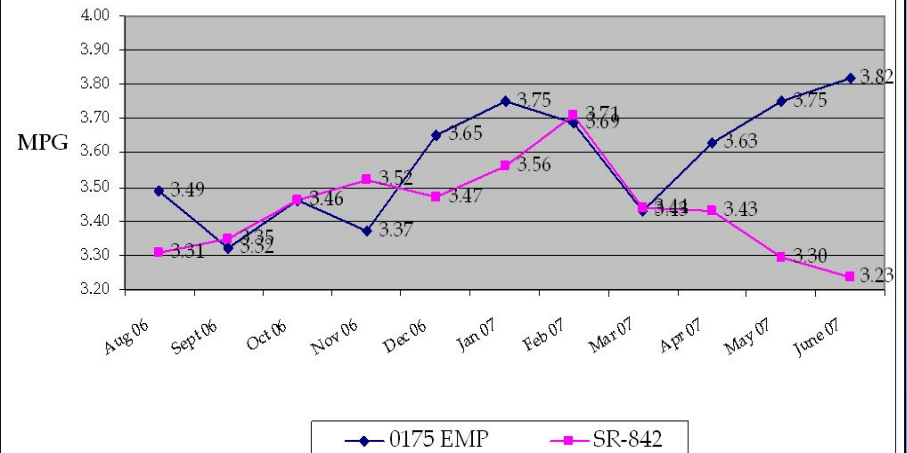
### New York City



### TRIMET Fuel Economy: EMP Test Buses and Reference Fleet Summer (May and June) 2007



### OMNITRANS



## Conclusion

There is an urgent need to reduce parasitic loads on the drivetrain

Electric components in the vehicle powertrain are more efficient than mechanical components when just meeting the standard systems performance

Adequate control of all major components allows cooling to be specific to engine requirements and further power loss reductions are obtainable

Advanced thermal management has been proven to be an excellent way of saving fuel and reducing emissions

Further gains will be obtainable after looking in depth at control, application specific cooling, component design and system layout

## References

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