Potential Efficiency Improvement by Accessory Load Reduction on Hybrid Transit Buses

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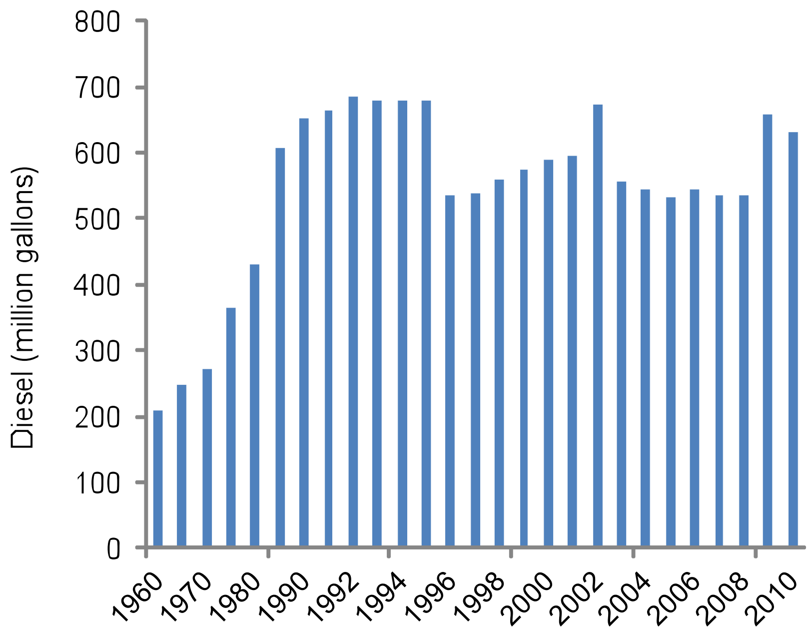
Transit Energy Use and Cost

- 633 M gallons diesel used for US transit in 2010 [1]
- Equivalent cost ≈ $2.5B at 2012 retail fuel prices



http://www.bts.gov/publications/national_transportation_statistics/

[1] RITA, *National Transportation Statistics Report*, 2012

Energy Use in Buses

- Significant power used for “Hotel Loads”
  - Air conditioning, steering, doors, cooling pumps, etc.
  - Currently inefficient, especially when stationary or moving slowly
  - Unclear how much and when power is actually needed
- This project – Auditing accessory energy use in a parallel hybrid bus

Electrification of Accessories

Published Work

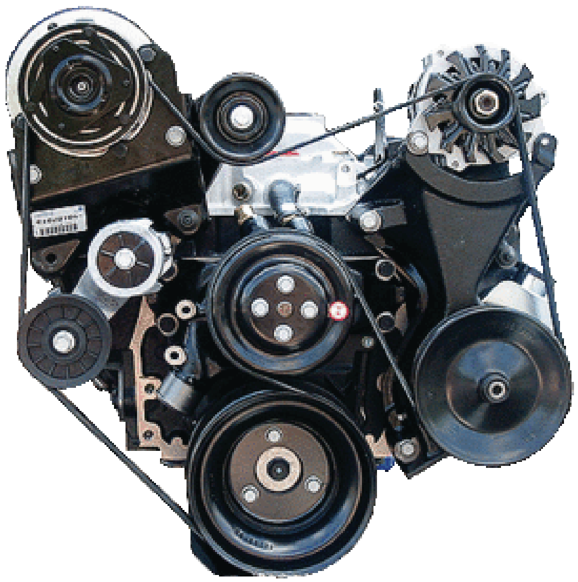
- Army [1]
  - 5-20% improvement
- EMP [2]
  - 5-10% improvement (CATA, TriMet)
- No work using actual vehicle monitoring

[1] Filipi, Z., Louca, L., Stefanopoulou, A, et al. “Fuel Cell APU for Silent Watch and Mild Electrification of a Medium Tactical Truck,” SAE paper 2004-01-147

[2] Page, R., Bedogne, R., Steinmetz, T., “A “Mini-Hybrid” Transit Bus with Electrified Cooling System.” SAE Paper 2006-01-3475, 2006

Accessory Efficiency Breakdown

- Parasitic Loading
  - More power to accessory than is required by its function
  - Accessory efficiency
- Accessory "Overdrive"
  - Accessories tied to engine speed
  - Sized for idle condition
  - Power increases with speed



http://www.shopfbparts.com/servlet/Detail?no=430

Experimental Test Plan

Data Aquisiton System

- NI Compact FieldPoint

Collection Details

- 10 day period
- Late summer
  - 145.6 hours of run time
  - Half a million timestamps
    - 39% AC on
    - 61% AC off

The Bus

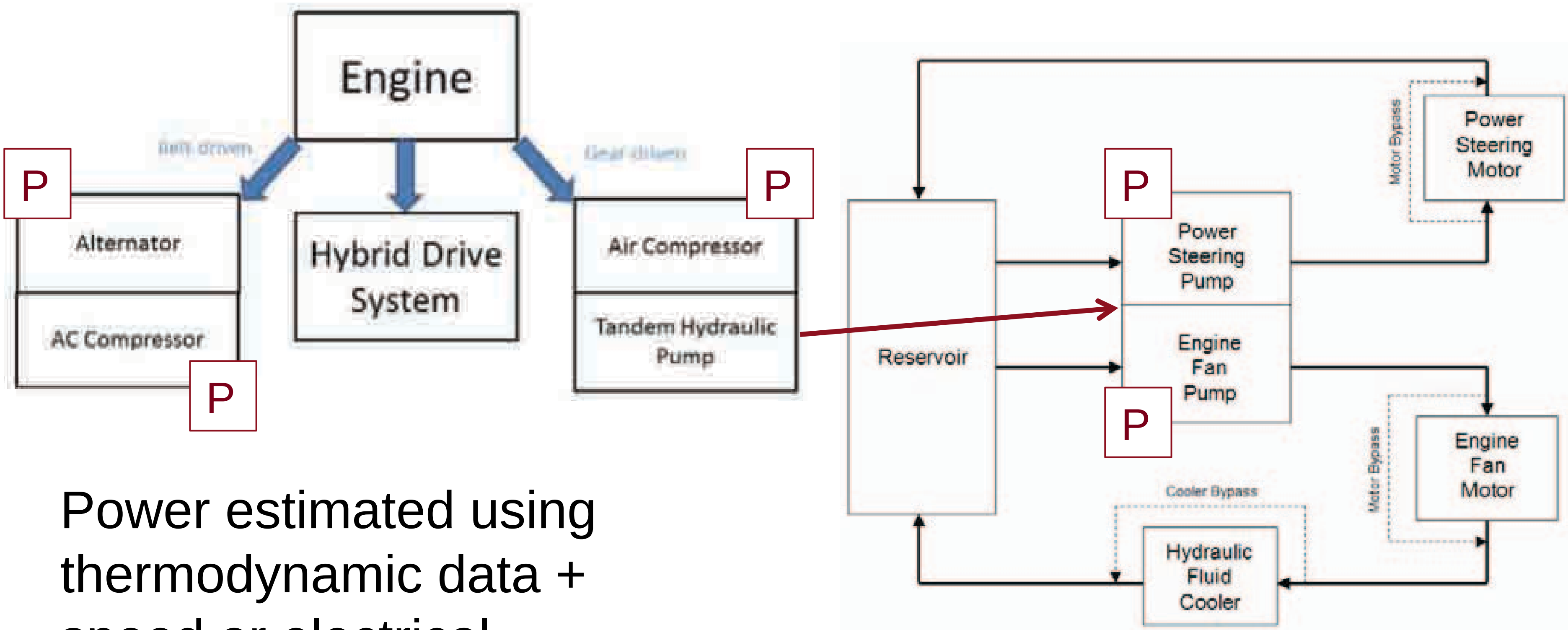
- 40' Gillig Low-Floor Bus
  - Parallel hybrid meeting 2007 emission standards
  - Purchased by Metro Transit: March 2008

Curb Weight:	29,550 lbs (13,400 kg)
Length	41.5 ft (12.6 m)
Width	8.3 ft (2.5 m)
Height/Height with Battery	9.0 ft/10.5 ft (2.7 m/3.0 m)
Wheelbase	23.3 ft (7.1 m)
Engine Type	2007 Cummins ISB
Rated Torque	620 lbf-ft (841 Nm) @ 1600 RPM
Rated Power	260 HP (194 kW)
Hybrid Drive System	Allison EP40
Passenger Capacity	38 seated, 28 standing

Accessory Drive Systems Monitored

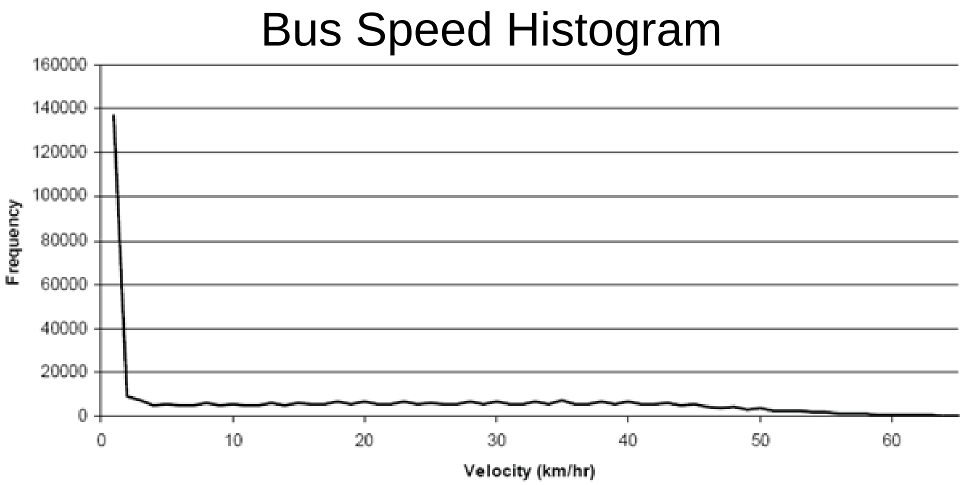
Directly driven systems

Systems powered by hydraulic drive



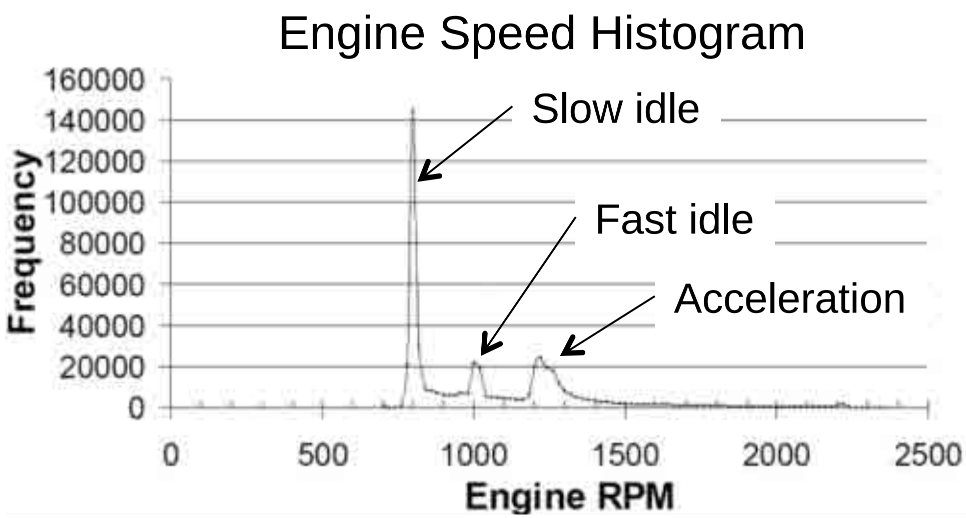
Power estimated using thermodynamic data + speed or electrical current

Results – Vehicle and Engine Histograms



- Bus Speed
  - Median = 8 km/hr
  - Mean = 16 km/hr

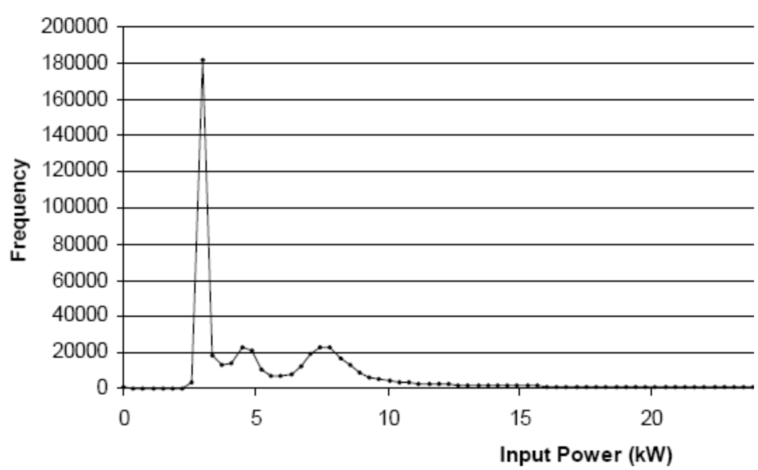
- 3 Engine Modes
  - Slow idle = 39%
  - Fast idle
  - Main hybrid propulsion



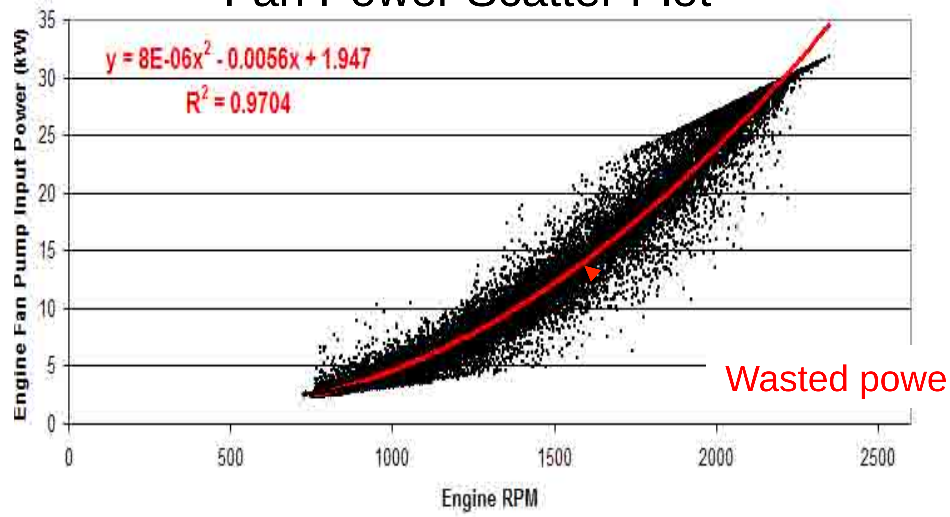
Results – Power Data

- Engine Hydraulic Fan Pump Example
  - Histogram and scatter plot
  - Power wasted at higher speeds
  - Average Input Power = 6.2 kW

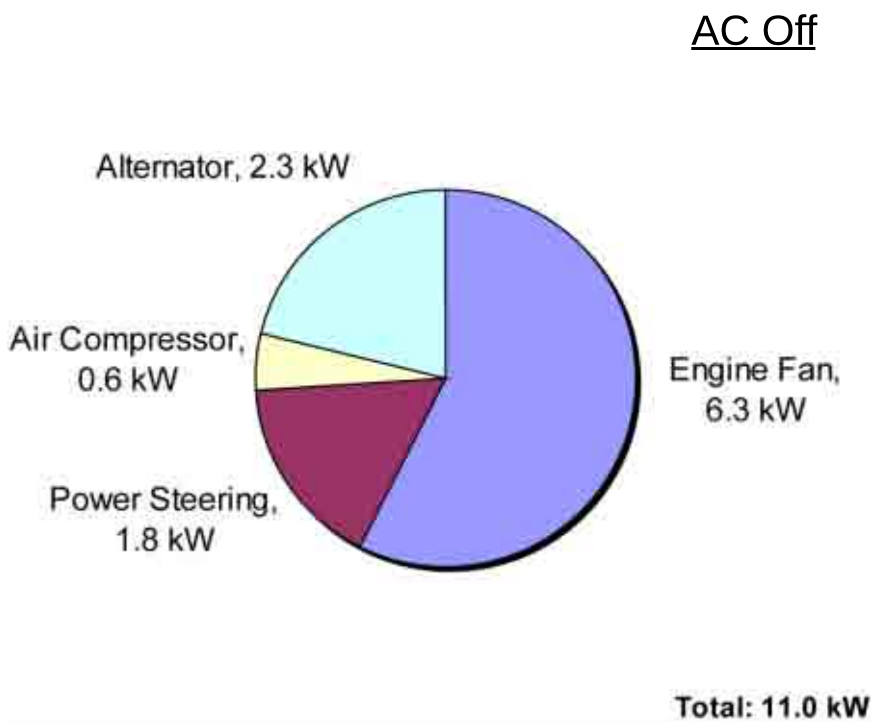
Fan Power Histogram

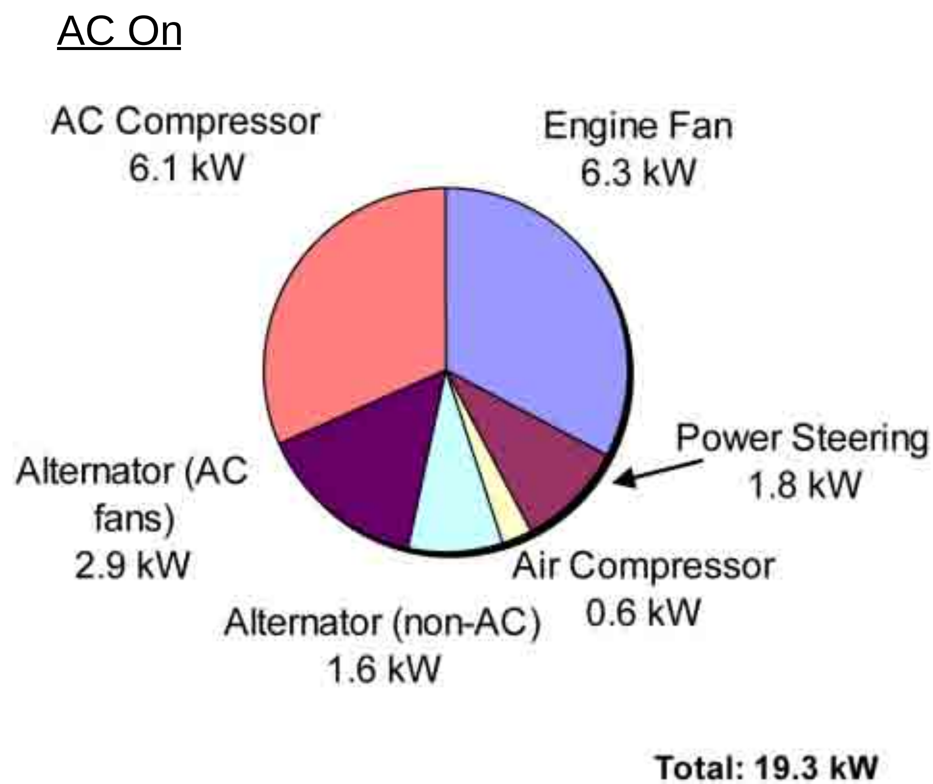


Fan Power Scatter Plot



Results – Average Accessory Loads





How much could we gain through accessory electrification?

Estimating Potential Savings

- Assumptions
  - Electrical accessories at idling power of mechanically-driven counterparts
  - Provides enough power to perform accessory's function at all times
  - Accessories decouple from engine speed when not needed

	Original Average Input Power (kW)	Theoretical Average Input Power (kW)	Average Load Reduction (kW)	Average Load Reduction (%)
Engine Fan Pump	6.3	3.2	3.1	49%
Power Steering Pump	1.8	1.2	0.6	34%
AC Compressor	0 / 6.1	0 / 4.1	0 / 2.0	33%
Air Compressor	0.58	0.29	0.29	50%
Alternator	2.3 / 4.5	2.3 / 4.5	0	0%
Total	**11.0 / 19.3**	**7.0 / 13.3**	**4.0 / 6.3**	**36% / 31%**

Engine fan and AC drive account for about 80% of potential savings!

Conclusions – Potential savings through accessory electrification

- Complete electrification of accessories could lead to 13-15% fuel savings
- Engine fan electrification should lead to a 5-10% improvement
- CO_2 emissions reductions = fuel savings

Next Steps

- Extend audit to 3 types of buses in the Metro Transit bus fleet
  - Standard diesel bus
  - Parallel hybrid bus
  - Fully electrified series hybrid bus
- Develop methods to analyze the collected data and methods to link it to data collected by Metro Transit.
- Use analyzed data to improve and calibrate models of bus performance and emissions.
- Examining the utility of using auxiliary power units (APUs) to generate this energy
- Installing and testing a high efficiency Diesel APU and eventually a solid oxide fuel cell APU

Questions?

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