Comparisons of the Latest HEV Test Procedures

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Test Procedure Proposal History

- 1990: CARB introduces HEV procedures (worst case)
- July 1992: A. F. Burke, GM presentation to EPA
- July 1992: SAE HEV Test Procedure Task Force (J1711) started
- 1994: CARB readdresses procedures, 1995 Draft report,
- 1994: J1711 issues first draft proposal
- 1994 to present: Argonne tests HEVs at EPA, GM, Ford, and Chrysler
- 1995: J1711 tested on university HEVs
- Feb 1998: reworked J1711 proposal ready for balloting
- Sep 1998: reworked CARB proposal on the books

Testing Purposes

- Vehicle Characterization
  - Research and analysis
  - Computer simulations

- Certification
  - Emissions: California Air Resources Board (CARB)
  - Fuel economy and emissions: U.S. Environmental Protection Agency (EPA)

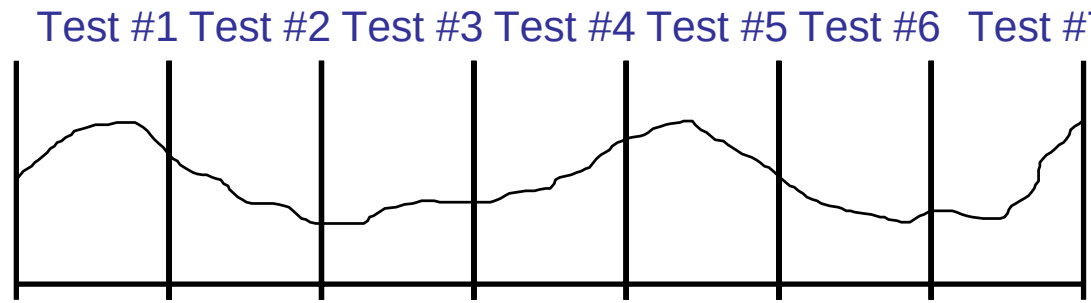
Significance of HEV Test Procedures

- Test procedures must accurately characterize vehicle capabilities and performance
- Procedures must not mistakenly give favorable results for one particular HEV design over another
- If procedures are not well thought out, manufacturers may build only procedure-friendly HEVs, eliminating many viable designs
- Argonne believes procedures should characterize vehicle, and let regulatory incentives occur in post-processing
  - ZEV operation
  - electrical energy conversion factors

HEV Testing Difficulties

- Unlike other recent vehicle advancements, HEV technology represents a giant leap in operational complexity
- HEV “design space” is so varied that one procedure does not fit all
- New instrumentation is needed
- Additional steps need to be taken

HEV's Transient Operational Nature



	Test #1	Test #2	Test #3	Test #4	Test #5	Test #6	Test #7
DSOC =	+4.5%	-13.5%	+4.5%	+12%	-7.5%	-9%	+18%
MPG =	33.4	65.3	33.4	27.7	49.5	52.7	24.4
1/MPG =	0.030	0.015	0.030	0.036	0.020	0.019	0.041

HEVs can exhibit test-to-test variation in fuel usage (and emissions)

Classifying HEVs

Before a suitable testing approach is taken, the vehicle must be categorized according to several questions:

1. Does the HEV regularly charge off-board?
2. Can the HEV sustain charge during test cycles?
3. Is the HEV capable of driving ZEV throughout the test cycle?
4. Does HEV use or store significant energy during test cycle?

Characterizing Vehicle vs. Characterizing Modes

- HEVs may have different passive or driver-selectable modes
- A typical input for mode decisions is battery state-of-charge (SOC)
- There are “charge-sustaining modes” and “charge-sustaining vehicles”; be clear when using these terms
- To characterize a single mode, the mode must last for an entire cycle
- The FTP is a vehicle characterization based on two tests
- Argonne recommendation is to accurately characterize modes first, then apply a strategy to weigh them

Test Approach for "Insignificant Energy Storage HEV"

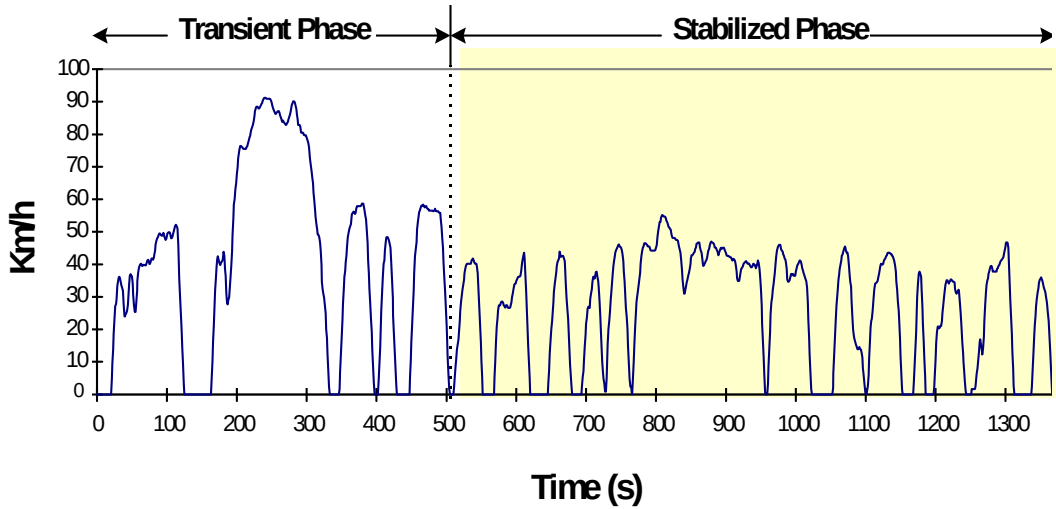
- Some new HEV designs have such low electrical energy usage that the vehicle can be treated as a conventional vehicle:
  - Honda HEV (VV) appears to be such a vehicle
  - CARB may consider testing the Honda HEV like normal (three-bag FTP)
  - No criteria yet exist to make this distinction.

Test Approach for Significant Energy Storage HEV”

- Three-bag FTP breaks down slightly; J1711 and CARB agree not to use the “505” bag shortcut; two full UDDS test are used
- HEVs with precise energy management control can be placed at a particular initial SOC that will nearly equal the ending SOC after a test cycle
- “Nearly equal” is defined; SAE J1711 and CARB use an energy window to define a valid test
  - (±1% of fuel energy used in cycle)
- SOC corrections are used for larger ΔSOCs

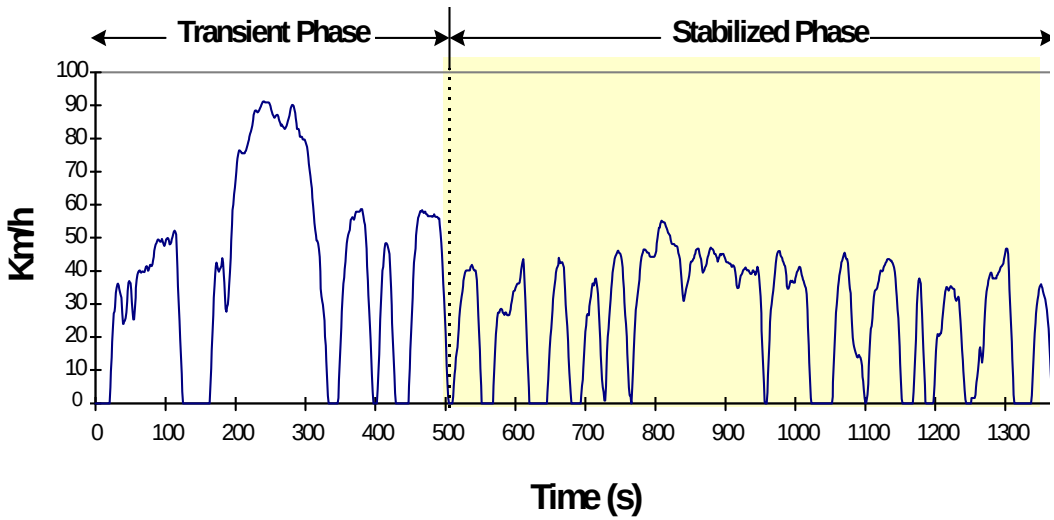
2 UDDS Tests Replace Three-Bag FTP

Cold-Start:



10 min. Soak

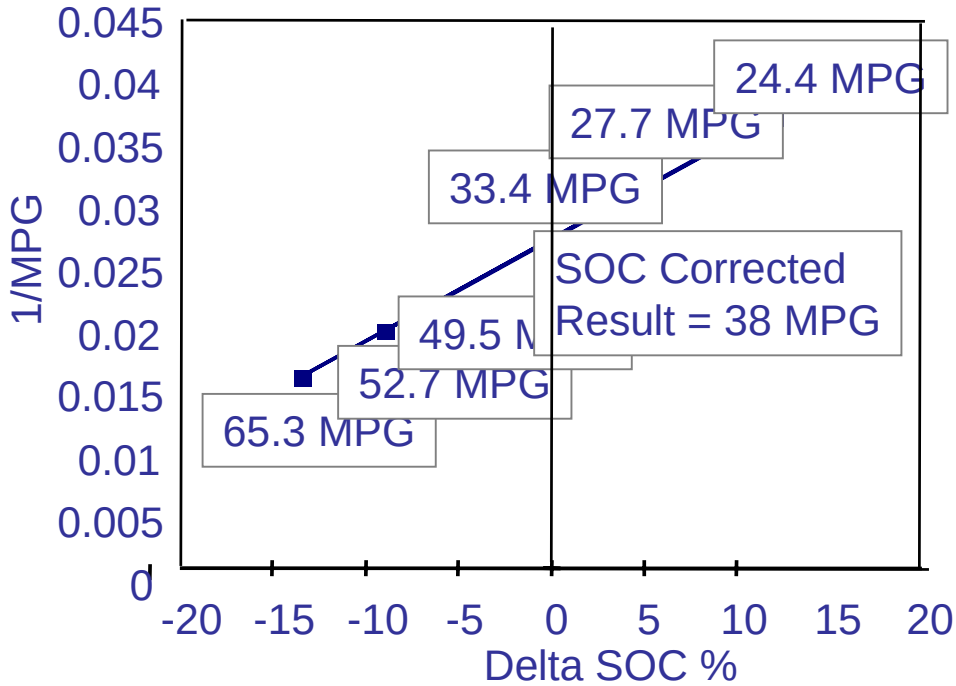
Hot-Start:



Second stabilized phase must be completed.

SOC Corrections

- SOC corrections are used for charge-sustaining operation
- J1711 includes SOC corrections as an option
- Argonne uses SOC corrections for prototype vehicles with unknown operational characteristics



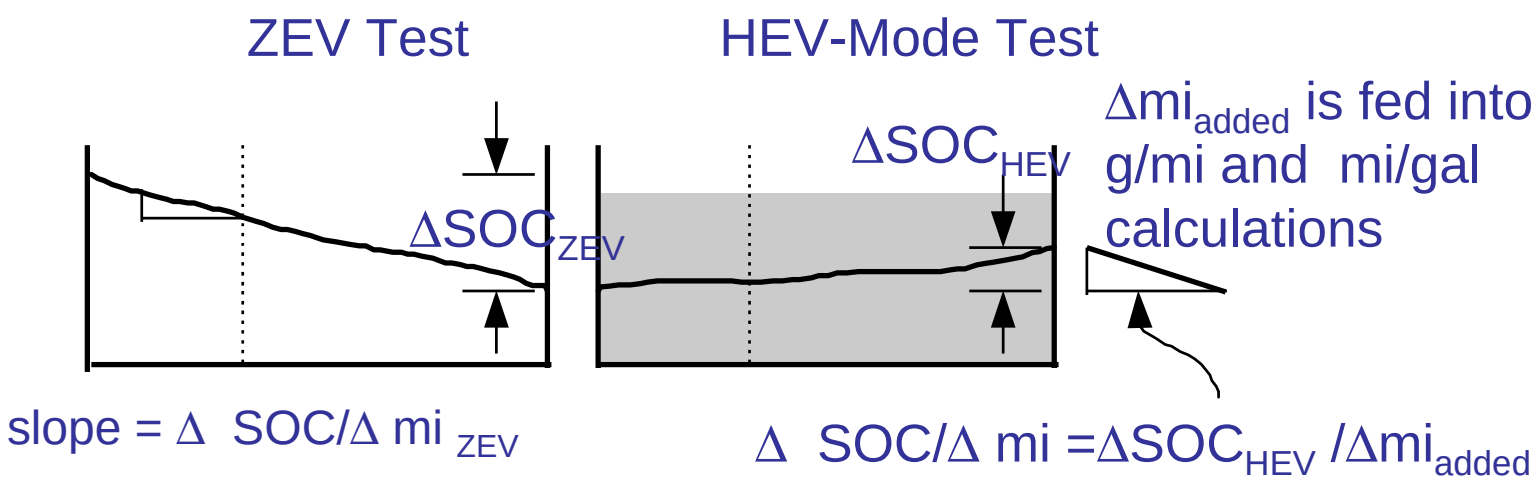
Note: simulated HEV test results from earlier slide

Test Approach for “ZEV Capable HEV”

- CARB procedure includes ZEV range test, then emissions test using energy window criteria
- J1711 uses 4 UDDS cycles in a row
  - Test labs are not necessarily receptive to long tests
  - Hot- and cold-start bag weighting is not consistent with current FTP or HEV “4-bag” FTP
- Argonne uses another SOC correction technique that blends ZEV operation with HEV operation

Argonne ZEV-Capable SOC Correction Method

- HEV must have ZEV range of one test cycle
- HEV must gain charge during HEV-mode test (likely for low initial SOC for HEV-mode test)
- Used successfully for four years of university prototype HEV testing



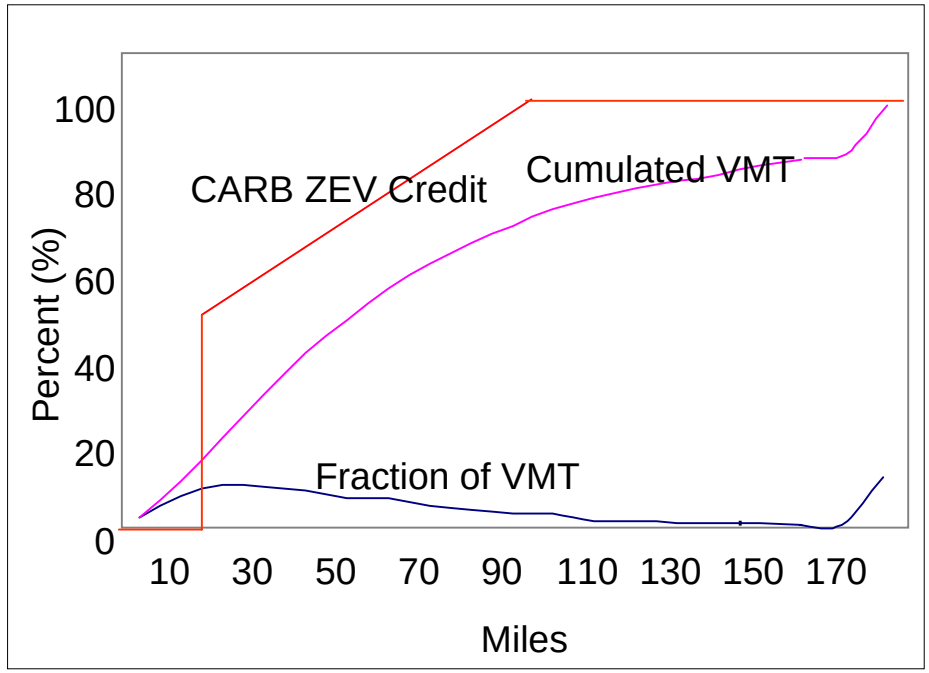
Charge-Depleting Operation

- Charge-sustainability is only defined for a given test cycle
- HEV designs may include one or more charge-depleting modes
- ZEV operation is a charge-depleting mode
- A charge-depleting vehicle cannot maintain charge during normal driving - this is not a practical design (e.g., range-limited EV)
- To characterize a charge-depleting mode, results must include both onboard fuel efficiency and electrical energy usage rate
- To characterize an off-board charged HEV, driver statistics can be used to weigh the amount of electrical energy usage with fuel energy usage

Driver Statistics Used to Predict ZEV Usage

1993 National Personal Transportation Survey
Daily Vehicle Miles Traveled (VMT)

Miles Bracket	% VMT	
5	3.2	3.2
15	8	11.2
25	10.4	21.6
35	10.1	31.7
45	9.4	41.1
55	7.6	48.7
65	7.5	56.2
75	5.7	61.9
85	4.8	66.7
95	3.9	70.6
105	4	74.6
115	2.4	77
125	2.3	79.3
135	1.7	81
145	1.6	82.6
155	1.9	84.5
165	1.3	85.8
175	1	86.8
185	0.9	87.7
195	0.7	88.4



- J1711 Uses 1995 NPTS to calculate a "Utility Factor"
- CARB allows partial ZEV credit toward ZEV mandate
  - ZEV range > 20 mi, credit linearly based on ZEV range test

Accounting for Off-Board Electrical Energy Use

- J1711 uses EV test procedure as precedent, direct energy conversion: 38.322 kWh AC energy from grid = 1 gallon of gasoline
- Using direct energy conversion yields very high equivalent fuel efficiencies for EV and ZEV operation (above 100 MPG)
- DOE HEV university competitions use power plant energy production and emissions rates applied to the AC kWh used
  - This analysis shows advanced ICE vehicles on par with advanced EVs
- CARB does not address fuel economy issues
- CARB considers ZEVs to be zero emission

Conclusions

- Development of test procedures is very difficult
  - HEV designs are extremely diverse
  - Limited access to real HEVs to test new concepts
  - Simulations and prototype HEVs were helpful
- Many current OEM designs are primarily low-energy-storage designs
  - High cost and weight of battery pack
  - Charge-dependent designs not considered widely consumer acceptable
- Existing procedures do address OEM HEVs currently announced

Conclusions (cont.)

- However, we must not lock in a procedure based on these early designs. Procedures must be allowed to evolve along with the technology.
- Controversy over certification (EPA and CARB) will emerge when ZEV-capable HEV designs are offered.
- Some lessons learned from light-duty work will apply to heavy-duty, but many decisions must be made about engine certification vs. vehicle certification.
- Argonne believes electrical energy conversion factors should be revisited for mpg ratings of electrical energy usage.

Useful References

- SAE J1711, *Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of HEVs*
- SAE 981080, *Investigation of Practical HEV Test Procedures with Prototypes from the 1997 FutureCar Challenge*, M. Duoba, Argonne National Laboratory
- SAE 950177, *Testing HEV Emissions and Fuel Economy at the 1994 DOE/SAE HEV Challenge*, M. Duoba, Argonne National Laboratory
- CARB light-duty vehicle test procedures and HEV test procedures: http://arbis.arb.ca.gov/regact/levii/levii.htm
- ADVISOR vehicle simulation model, NREL System Analysis Web site: http://www.ctts.nrel.gov/analysis
- EPA420-R-98-006, *Evaluation of a Toyota Prius Hybrid System*, August 1998