

Motion Base Simulation of a Hybrid-Electric HMMWV for Fuel Economy Measurement (2008-01-0775)

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Outline

- Motivation and Purpose
- Experiment Design
- Simulation Architecture and Design
- Results and Conclusion

Hybrid Electric Vehicle Experimentation and Assessment (HEVEA) Program

MOTIVATION

- Develop HEV Test Operating Procedure (TOP) for Military Vehicles
- Determine the fuel economy benefits of hybrid electric vehicles using quantifiable test data
- Provides Test Data to Validate TARDEC DCE-TOP Simulations

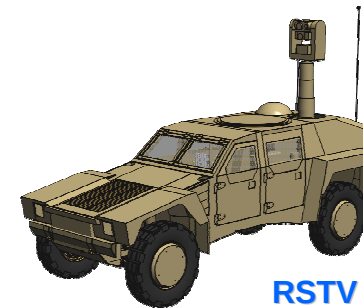
Conventional:

- 2 - HMMWVs,
- 2 -21/2T LMTVs
- 1 - 5T MTV
- 1 – FMTV CVT
- 2 - HEMTTs
- 1 – AM GEN UV



Hybrid Electric:

- 1 – HMMWV
- 1 – RSTV
- 1 - IMG UV
- 1 – LM UV
- 1 – AH/SS MSV
- 1 – BAE FMTV
- 1 – OSHKOSH HEMTT “A3”



RSTV Series HE



Parallel Hybrid MSV



2-Parallel hybrid UV's



2008-01-0775

Experiment Purpose

- To replicate fuel economy measurements being performed under the HEVEA program.
- Focus on one conventional vehicle and one hybrid-electric vehicle.
- Assess the ability of modeling and simulation tools to measure fuel economy.

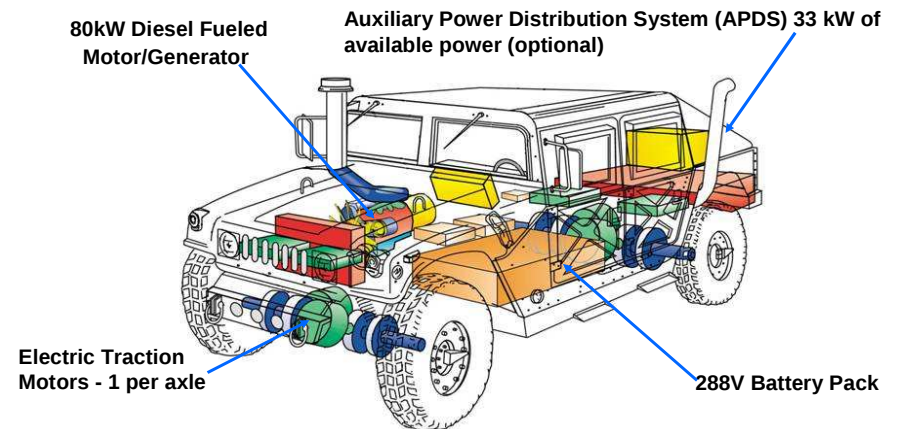
Experimental Design: Vehicles

M1113



- Conventional
- 5,216 kg (11,500 lbs) GVW

XM1124



- Series hybrid-electric
- 5,216 kg (11,500 lbs) GVW

HMMWV Power-Train Components

M1113 Conventional:

GM / GEP 6.5 L Turbo-Diesel

≈ 145 kW @ 3200 rpm

GM 4L80-E Automatic Trans.

≈ 4 Spd. Overdrive

≈ Conv. Lockup 3rd & 4th

2-Spd. Transfer-Case

XM1124 Series Hybrid:

Peugeot 2.2 L Turbo-Diesel

≈ 100 kW @ 4000 rpm

UQM SR-286 PM Generator

≈ 85 kW Cont Output

Saft VL30P LiOn Battery Pack

≈ 300 V, 60Amp-Hr

UQM SR-286 Traction Motors

≈ 550 N-M Peak Torque

Common Components:

Torsen Differentials

Reduction Hubs (1.92:1)

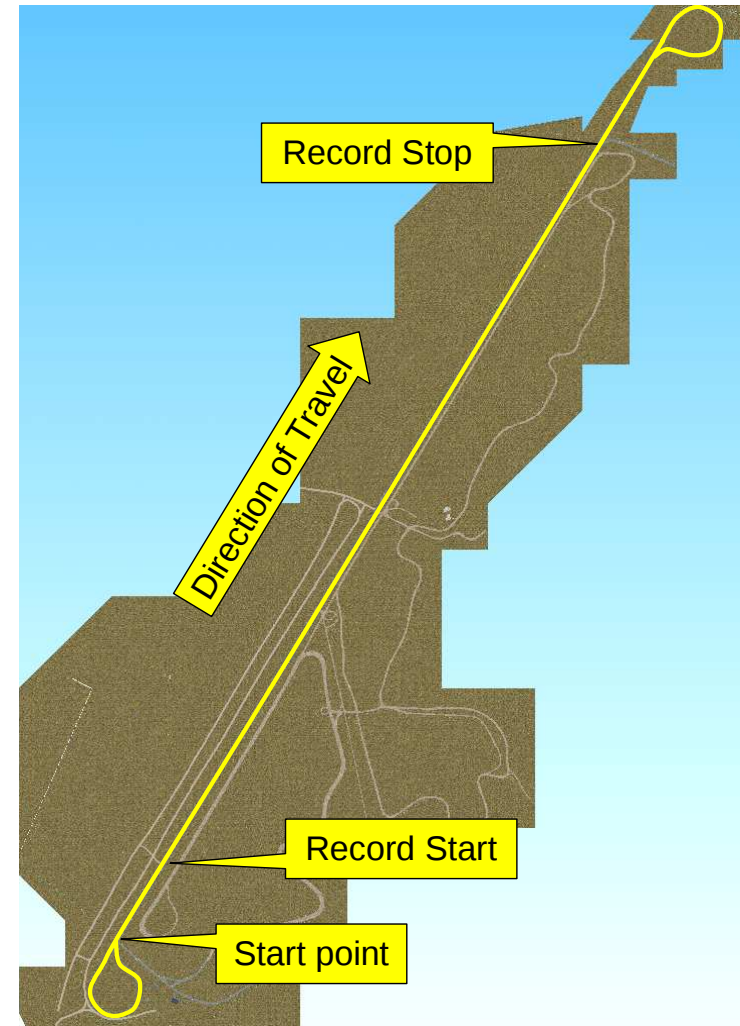
Experimental Design: Terrains

Four Terrains used:

- Perryman Paved
- Harford Loop
- Munson SFC
- Churchville B

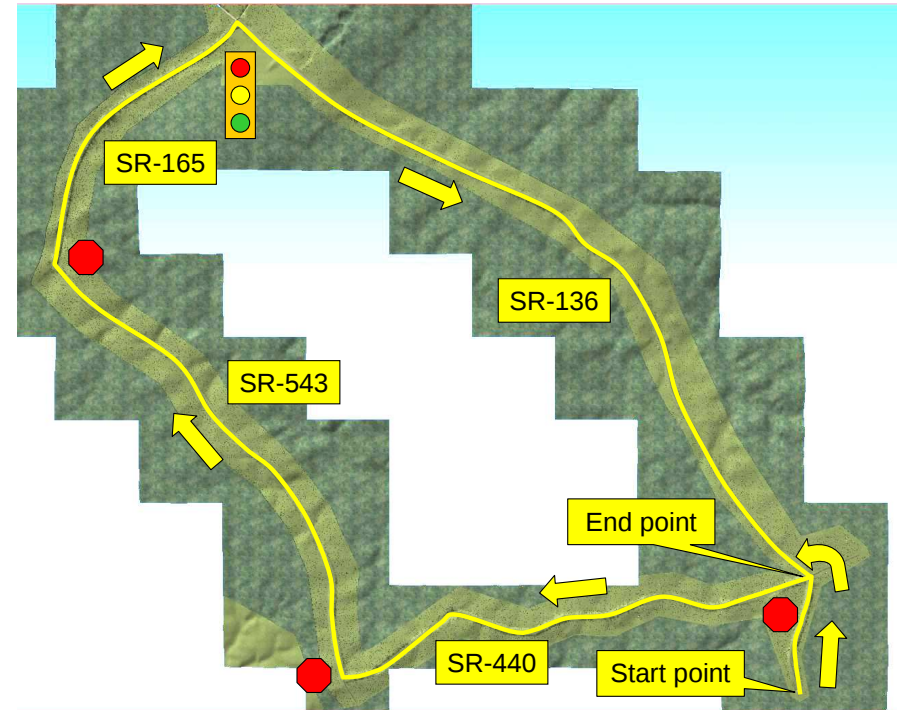
Perryman Paved

- Level paved straight road
- Loop-to-Loop distance is 2 mi (3.2 km)
- Record on 1.5 mi (2.4 km)
- Speeds ranged from 10 to 60 mph (16 to 97 kph)
- 5 mph (8 kph) speed increments.



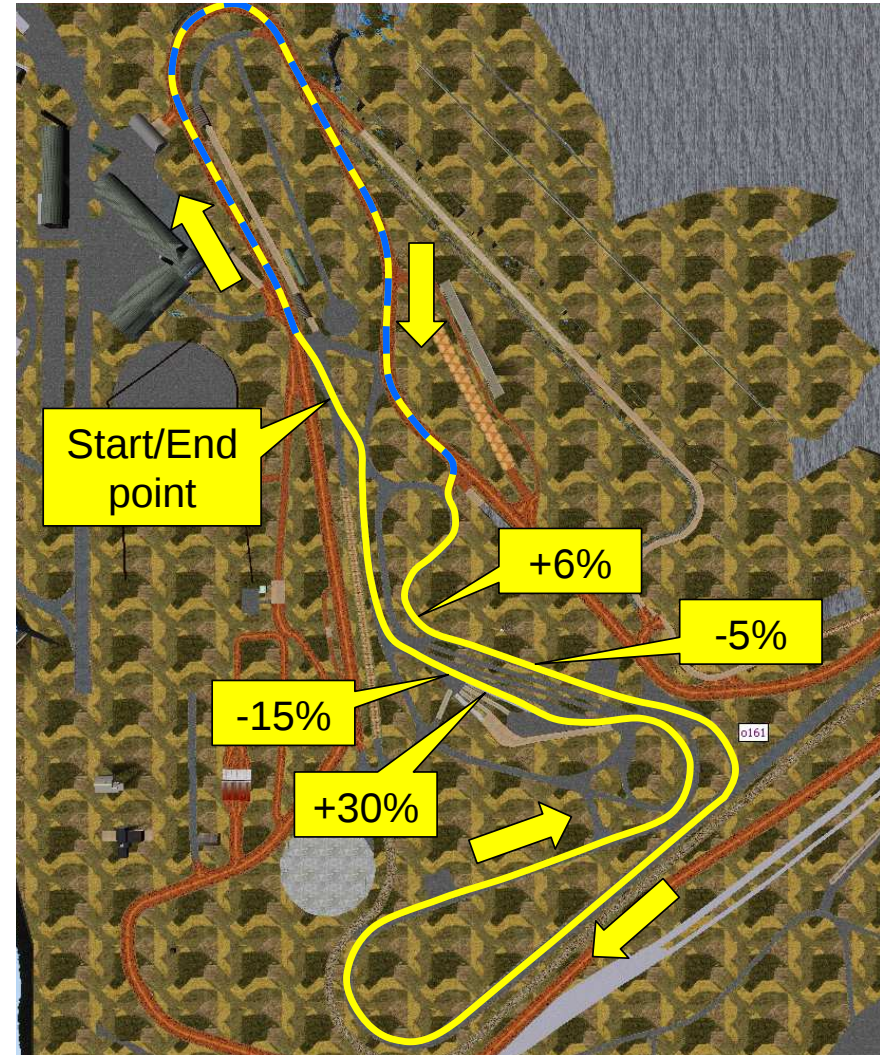
Harford Loop

- Closed circuit of public road in Harford County, MD
- 4 stops
- 17.6 mi (28.3 km)
- Run CW
- Course run at posted speeds which varied from 30 to 50 mph (48 to 80 kph).
- 463 ft. (141 m) change in elevation.
- 3.3% mean absolute grade.
- -15% to +18% grade range.



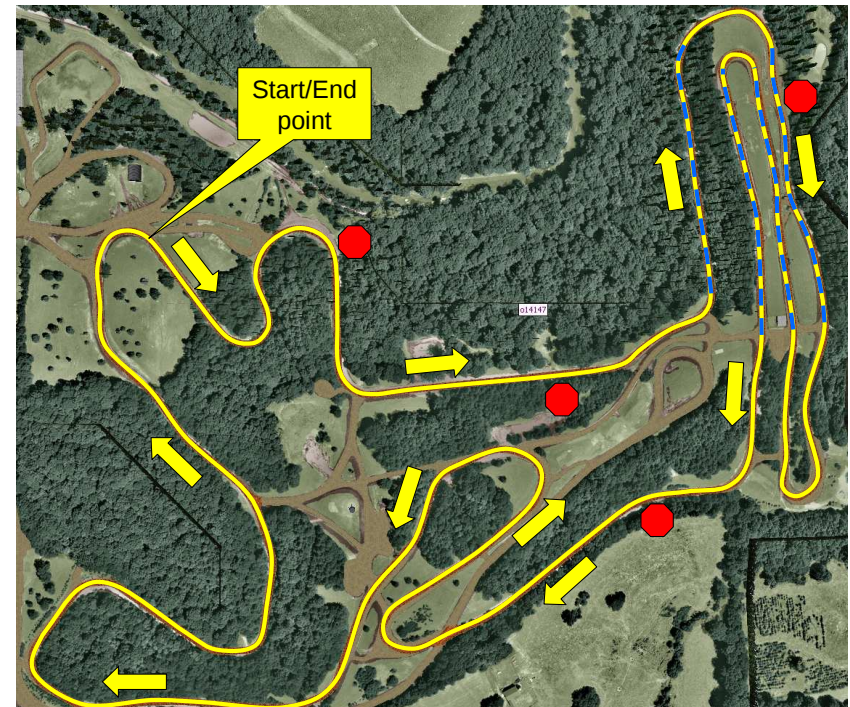
Munson Standard Fuel Course (SFC)

- Closed course at Aberdeen
- Part gravel, part paved
- 1.67 mile (2.7 km) closed loop
- Run CW
- Speeds from 10 to 30 mph (16 to 48 kph).
- 5 mph (8 kph) speed increments.
- 42 ft. (12.7 m) change in elevation.
- 2.5% mean absolute grade.
- -15% to +30% grade range.



Churchville B Course

- Closed course at Aberdeen
- All gravel w/ moguls
- 3.7 mile (6 km) closed loop
- Run CW w/ 4 stops
- Speeds from 10 to 25 mph (16 to 40 kph).
- 5 mph (8 kph) speed increments.
- 189 ft. (57.7 m) change in elevation.
- 8.9% mean absolute grade.
- -23% to +29% grade range.



Experiment Design

Variable	Scope	Values
Vehicle	-	M1113, XM1124
Terrain	-	Harford Loop Perryman Paved Munson SFC Churchville B
Speed	Not varied for Harford Loop	Perryman: 10 – 60 mph Munson: 10 – 30 mph Churchville: 10 – 25 mph
Driver	-	A, B
Initial SOC	XM1124	High: ~80% Low: ~50%

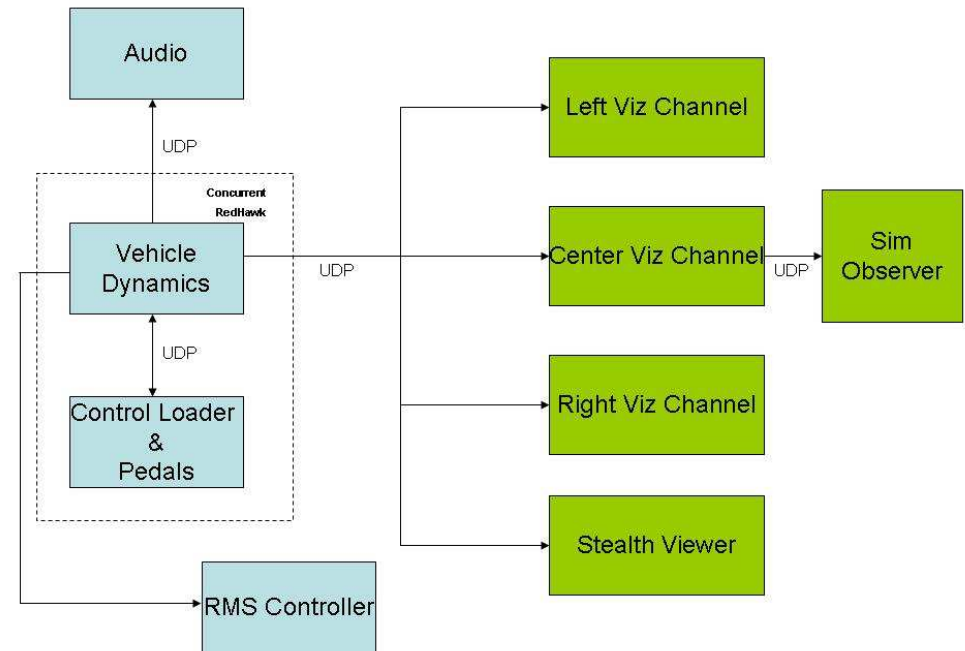
Execution Matrix

	Perryman Paved				Harford Loop			Munson			Churchville		
Speed	M1113	XM1124			M1113	XM1124		M1113	XM1124		M1113	XM1124	
mph (kph)		50	60	80		50	80		50	80		50	80
10 (16.1)													
15 (24.1)													
20 (32.2)													
25 (40.2)													
30 (48.3)													
35 (56.3)													
40 (64.4)													
45 (72.4)													
50 (80.5)													
55 (88.5)													
60 (96.6)													

74 runs per driver

Architecture and Design

- Motion: RMS
- Visuals:
 - ≡ Commercial IG
 - ≡ 900 MHz, 768 MB Graphics Card
 - ≡ 22" 1680x1050 LCD display
- Dynamics:
 - ≡ Commercial Multi-body Dynamics
 - ≡ Commercial Power Train modeling package.
- Infrastructure:
 - ≡ Commercial simulation integration package.
 - ≡ 100Base/T Ethernet and fiber-optic network
- Driver Interface:
 - ≡ HMMW BUC
 - ≡ Steer loading
 - ≡ Accelerator, brake.



Architecture and Design: RMS

- Ride Motion Simulator (RMS)
- 6 DOF
- Single occupant
- Hydraulically powered.
- 40 Hz bandwidth



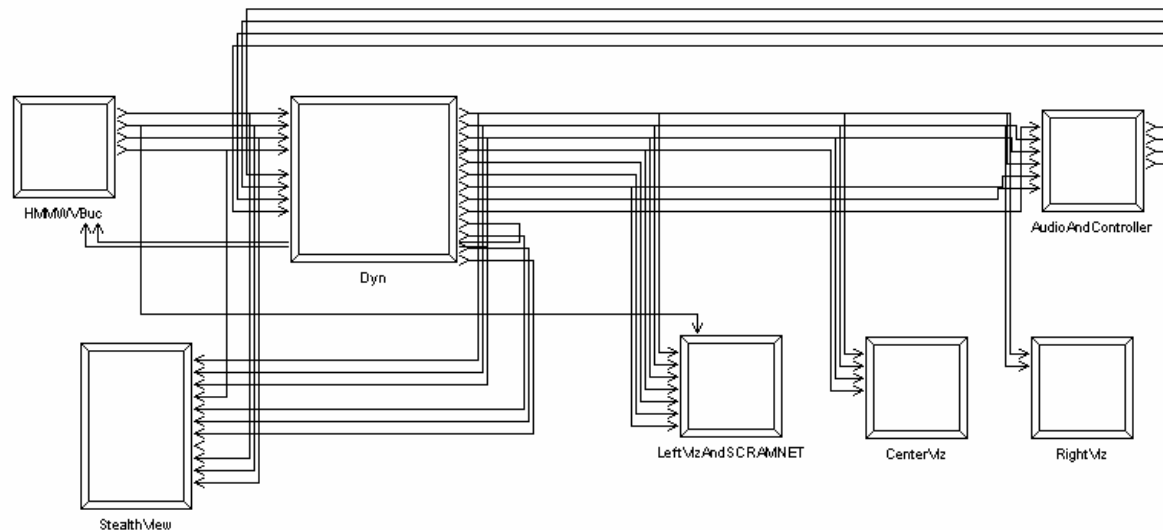
Architecture and Design: Visuals/BUC

- Three monitors at 35° angles
- 5 ms response time
- 60 – 100 Hz update
- Control loading
- Throttle position is sensed
- Brake position is sensed



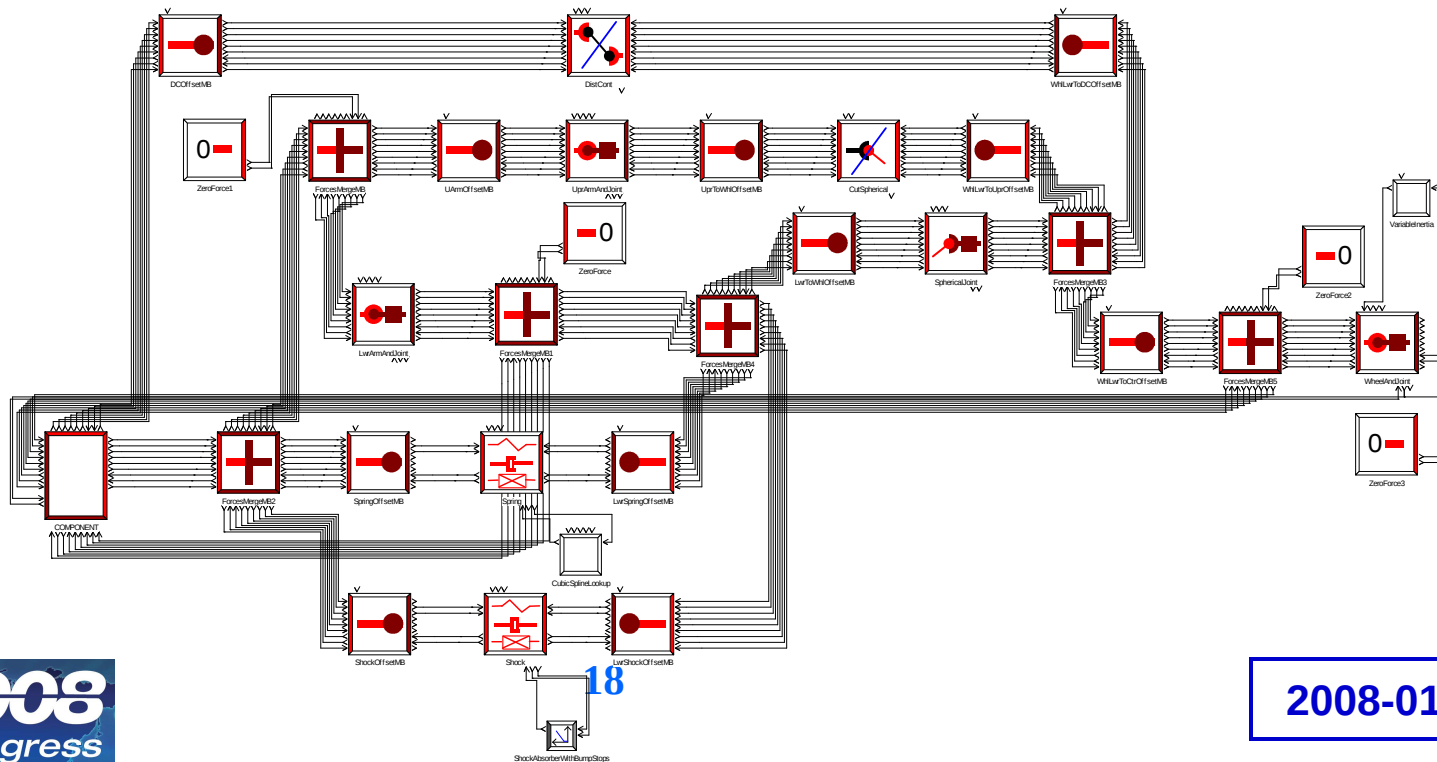
Architecture and Design: Infrastructure

- Program distributed across 7 processes running on 6 computers.
- Commercial simulation integration package is used to distribute data over Ethernet.



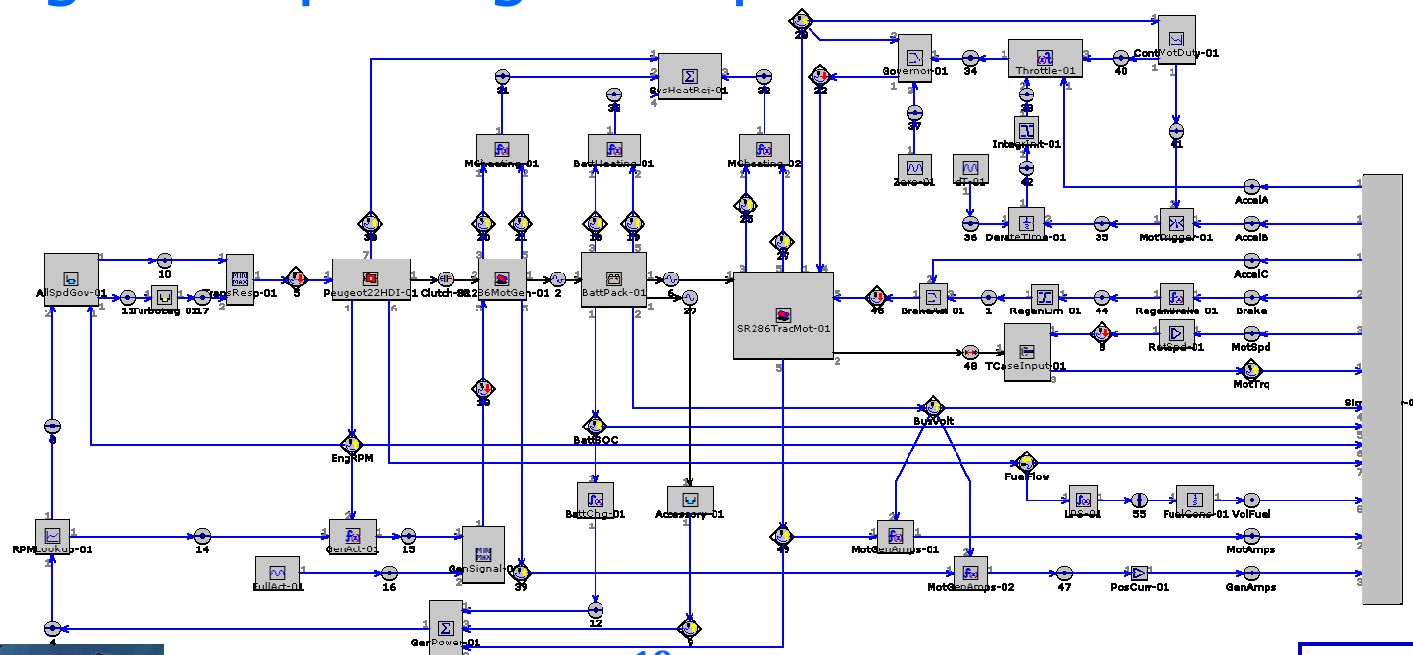
Architecture and Design: Vehicle Dynamics

- 22-body model using a commercial real-time code
- Full suspension and steer kinematics
- Mass properties matched to APG vehicles
- Same model used for M1113 and XM1124

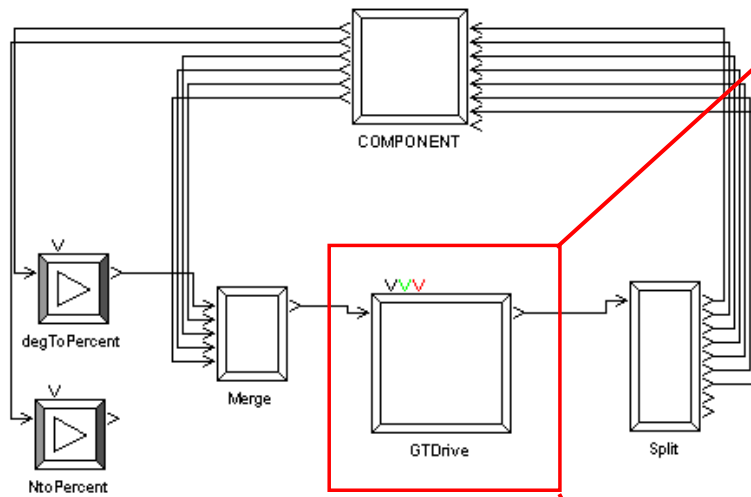


Architecture and Design: Power Train

- Two different power train models developed using a commercial modeling package.
- Model developed and exported as a real-time file
- Real-time model was then wrapped in an integration package component



Dynamics/Power Train Integration

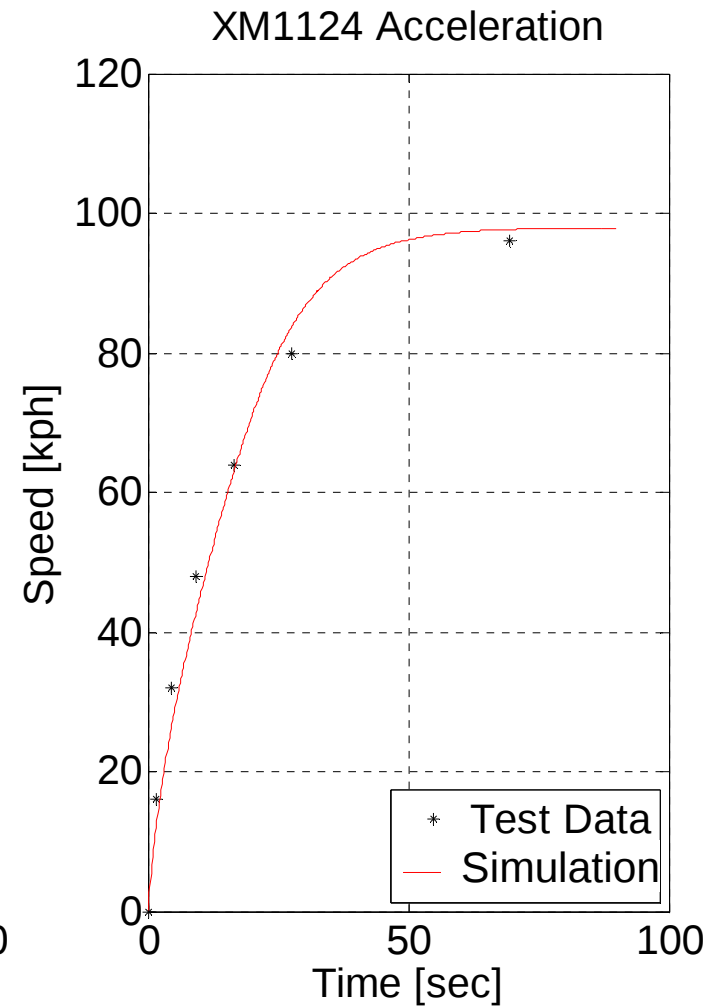
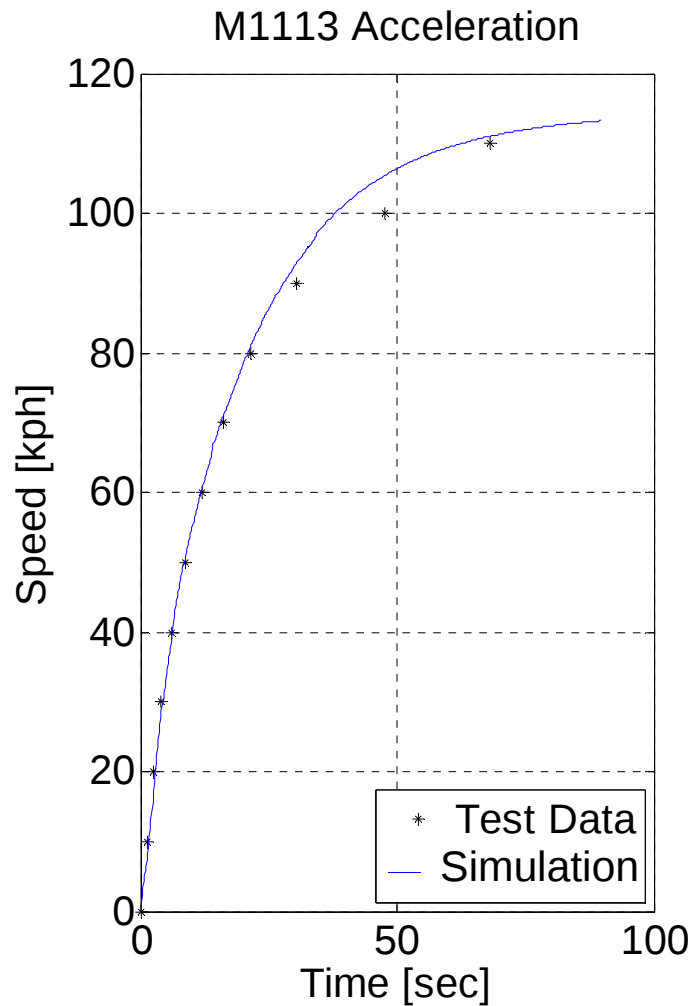


- Powertrain Real-time library is linked into the commercial integration framework.
- Exported file is loaded by **gtstartup()**.
- The dynamics and power train integrate their own states.

```

BEGIN_INIT
...
  gtstartup( "M1113RT", 7, "GTdrive", 7,
    &ireqcase, &gtidur, &jrtmsg );
END_INIT
BEGIN_OUTPUTS
...
  for(i=0; i < SMEM(inpwidth); i++ ) {
    udum[i] = (double)INPUTV(gtInp)[i];
  }
  gtadvance( &SMEM(deltaTime),
    &SMEM(nInp), udum, &sldone, &iadv );
  gtupdate(ydum);
  for(i=0; i<SMEM(nOut); i++ ) {
    OUTPUT(gtOut)[i] = (SimRealVar)ydum[i];
  }
}
END_OUTPUTS
BEGIN_STOP
  long sunflag=0;
  slclose(&sunflag);
END_STOP
    
```

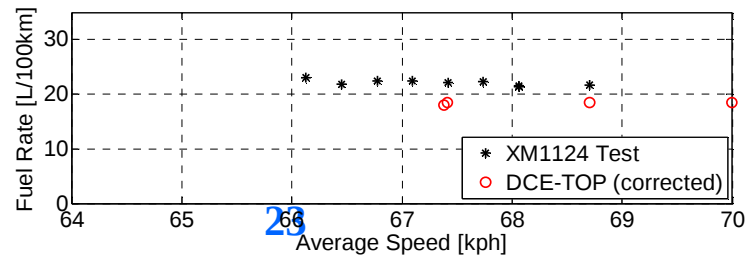
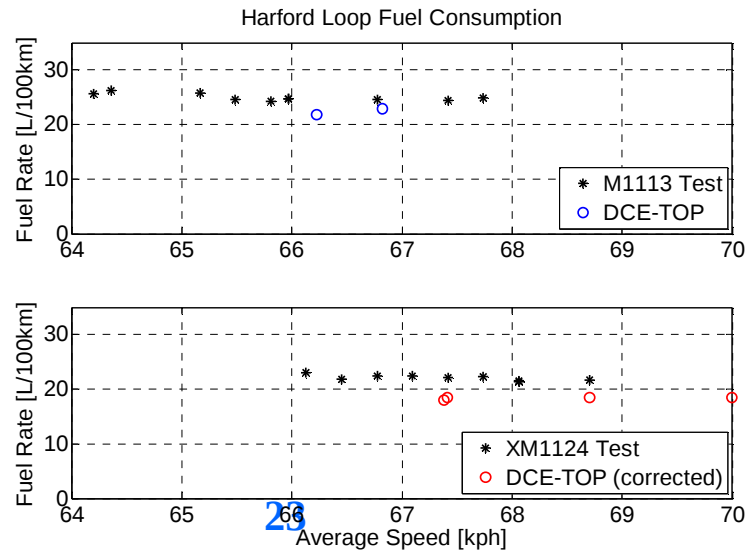
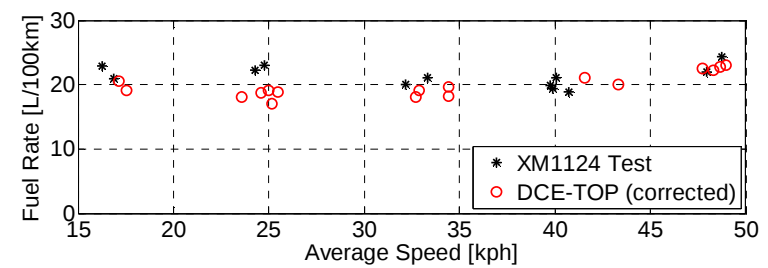
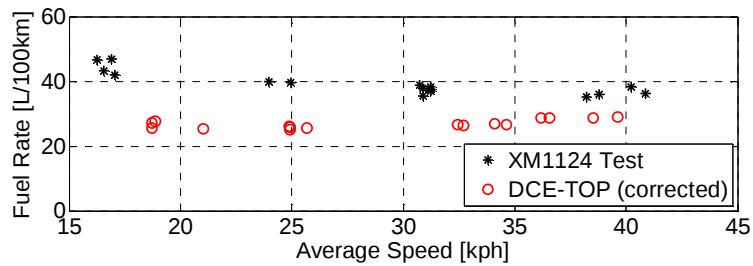
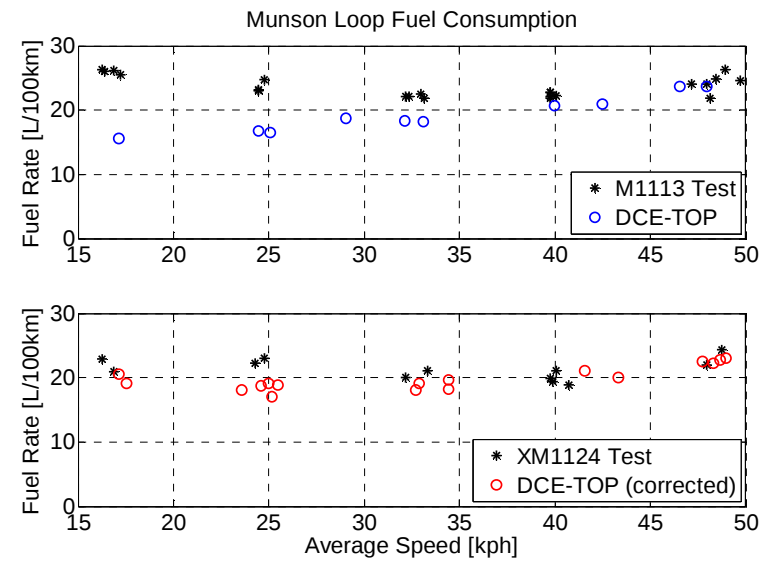
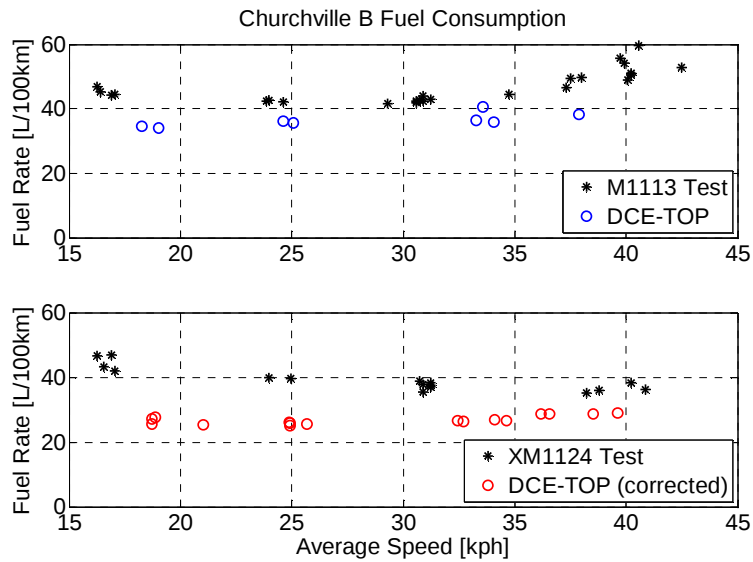
Power Train Validation



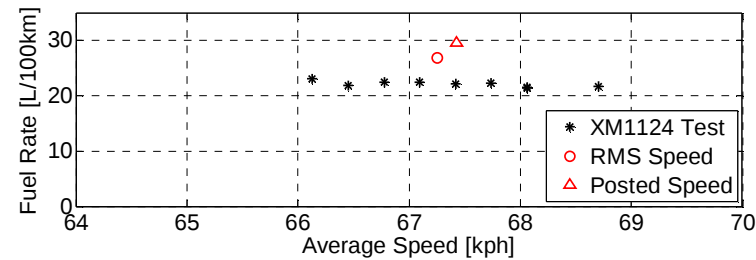
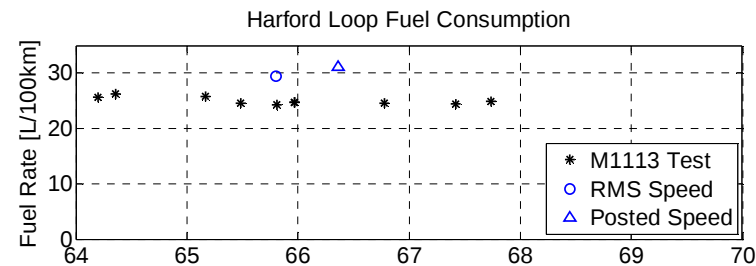
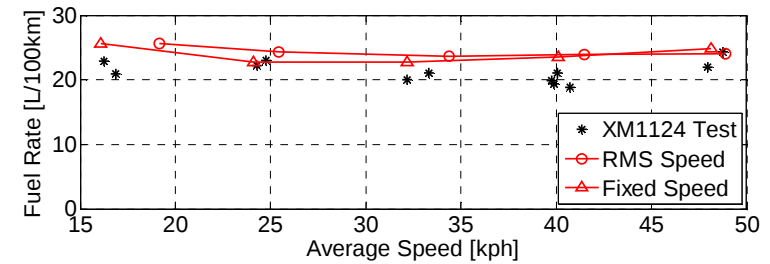
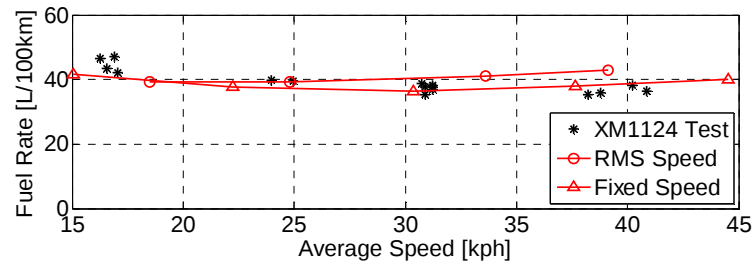
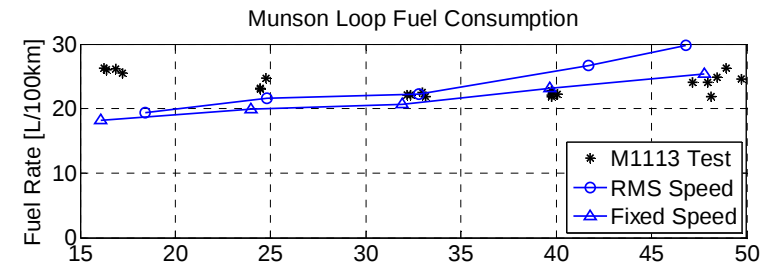
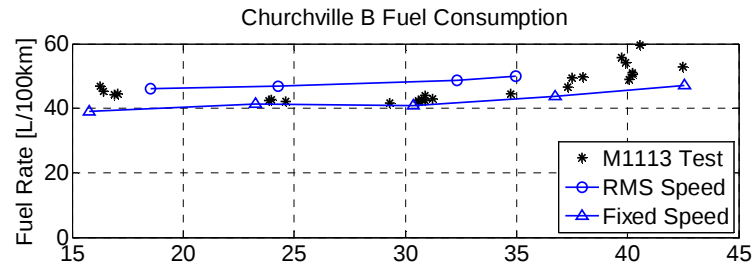
Results

- 2 drivers from APG participated.
- 166 runs completed
- Fuel economy: Total Fuel / Total Distance
- For the XM1124 the total fuel was corrected by: $\Delta f = -F_{\text{corr}} (\%SOC_{\text{final}} - \%SOC_{\text{initial}})$
Where $F_{\text{corr}} = 0.05407 \text{ L}/\%$ for SOC decrease
And $F_{\text{corr}} = 0.06369 \text{ L}/\%$ for SOC increase

Results: Initial



Results: Final



Conclusion

- An experiment was designed to measure fuel economy for a conventional and hybrid electric HMMWV.
- It incorporated the integration of a high fidelity vehicle dynamics model with a high fidelity power train model.
- Duty cycles were recorded to future off-line analysis.
- Fuel economy predictions varied with speed and terrain.