CHRYSLER ECOVOYAGER SIMULATION

http://www.leapcad.com/Transportation/Chrysler_EcoVoyager_Simulation.mcd

Ecovoyager - Vehicle, Motor, Road, and Enviro Params: ***Fixed Gears:*** **6,000,8000 RPM Pk Power**

Max Motor Power:	$Power_{max} := 268 \cdot hp$	Fixed Two Gear Ratios:	$GR_1 := 14.3 \quad GR_2 := 7.4$
Max Motor Torque:	$T_{max} := 250 \cdot ft \cdot lbf$	Battery Energy:	$Energy_{bat} := 16 \cdot kW \cdot hr$
$GR_{1.5} := 8.2752 \cdot 1.124$		Tire Radius*:	$r_{tire} := \frac{30.3}{2} \cdot in$
Max Force, FMaxTire	$Fm_{tire1} := GR_1 \cdot \frac{T_{max}}{r_{tire}}$	$Fm_{tire2} := GR_2 \cdot \frac{T_{max}}{r_{tire}}$	$Fm_{tire1.5} := GR_{1.5} \cdot \frac{T_{max}}{r_{tire}}$
$RPM := min^{-1}$			
Max Power, ω:	$\omega_{Pmax} := \frac{Power_{max}}{T_{max}}$	$RPM_{Pmax} := \frac{\omega_{Pmax}}{2 \cdot \pi}$	$RPM_{Pmax} = 5.63 \times 10^3 RPM$
Constant Power vehicle velocity, v_{CP}:	$v_{CP} := \frac{Power_{max}}{Fm_{tire1.5}}$	$v_{CP} = 54.565 \, mph$	$Power_{max} = 268 \, hp$
		Lotus Elsie Chassis	$k := 10^3$
Time, in seconds:	$t := 0, 0.5 .. 30$	Curb Weight:	$M_{curb} := 2750 \cdot lb$
Time unit:	$\tau := 1 \cdot sec$	Average Wind Velocity:	$Vw := 0 \cdot mph$
Drag Coeff:	$Cd := 0.35$	Effective Cross Wind V:	$V_{cw} := 0 \cdot mph$
Cross Wind Drag Coff:	$Cd_{cw} := 0.000014$	Frontal Area*:	$Afg := 59 \cdot in \cdot 70 \cdot in$
Shape Correction Factor:	$SCF := 1$	Frontal Area	$Af := Afg \cdot SCF \quad Af = 2.665 \, m^2$
Air Density:	$\rho := 1.293 \cdot \frac{gm}{liter}$	Tire Rolling Resist, Hys:	$RR_{tire} := 0.009 \quad T_{hys} := 0 \cdot \frac{sec}{m}$
Road Rolling Resist:	$RR_{road} := 0.002$	θ (radians):	$\theta := atan(0.0)$
$Passengers2 := 170 \cdot lb$	$M_{batt} := \blacksquare \, lb$	$M_{gross} := M_{curb} + Passengers2$	
Rotational Inertia Coeff:	$k_m := 1.12$		$M_{gross} = 2.92 \times 10^3 \, lb$

Vehicle Dynamics Equations:

Velocity at Torque Fall: $v_{T1} := 6100 \cdot RPM \cdot 2 \cdot \pi \cdot r_{tire} \cdot GR_1^{-1}$ $\quad v_{T1} = 38.452 \, mph$

Velocity to RPM: $VtoR(v) := v \cdot (k \cdot 2 \cdot \pi \cdot r_{tire} \cdot RPM)^{-1}$ $\quad VtoR(61 \cdot mph) \cdot GR_2 = 5.008$

Road Resistance, Ft: $Ft(v) := M_{gross} \cdot g \cdot \left[T_{hys} \cdot v \cdot \sin(\theta) + (RR_{tire} + RR_{road}) \cdot \cos(\theta) + \sin(\theta)\right]$

Air Drag Force, Fa: $Fa(v) := 0.5 \cdot \rho \cdot Cd \cdot Af \cdot \left[(v + Vw)^2 \cdot Cd + Cd_{cw} \cdot (V_{cw})^2\right]$ $\quad \omega_{fall} := 6 \cdot RPM$

Opposing Force, Fo: $Fo(v) := Fa(v) + Ft(v)$ $\quad Fo(60 \cdot mph) = 66.25 \, lbf$ $\quad \omega_{fall} := RPM_{Pmax} \cdot k^{-}$

Torque/Force Drop Curve: $T_{fall}(\omega) := T_{max} \cdot \left[1 - (\omega \cdot RPM - \omega_{fall}) \cdot \left((\omega_{max} - \omega_{fall})\right)^{-1}\right]$ $\quad \omega_{max} := 16 \cdot RPM$

Torque Speed Relation: $T_m(\omega) := if(\omega \cdot RPM \geq \omega_{fall}, T_{fall}(\omega), T_{max})$

Net Tractive Force: $F_t(v) := if\left(v > 1000 \cdot mph, GR_2 \cdot \frac{T_m(VtoR(v) \cdot GR_2)}{r_{tire}}, GR_{1.5} \cdot \frac{T_m(VtoR(v) \cdot GR_{1.5})}{r_{tire}}\right)$

$P_m(\omega) := T_m(\omega) \cdot k \cdot 2 \cdot \pi \cdot \omega \cdot RPM$

Third Law of Motion:
(a is acceleration) $a(v) := \frac{F_t(v) - Fo(v)}{k_m \cdot M_{gross}}$ $\quad Power_{max} := P_m(8)$ $\quad Power_{max} = 293.777 \, hp$

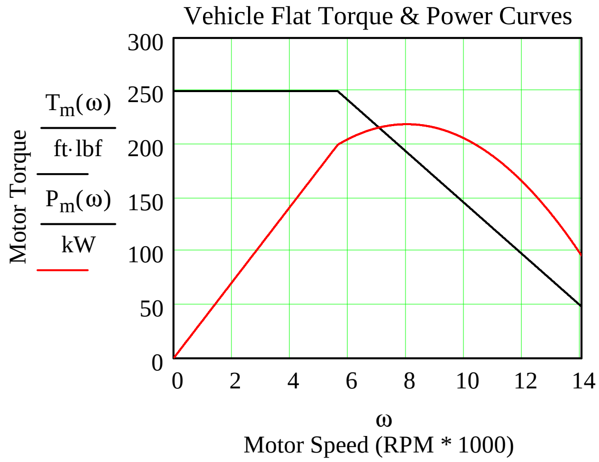
Applying maximum motor torque, find the velocity starting from initial velocity = 0 mph.

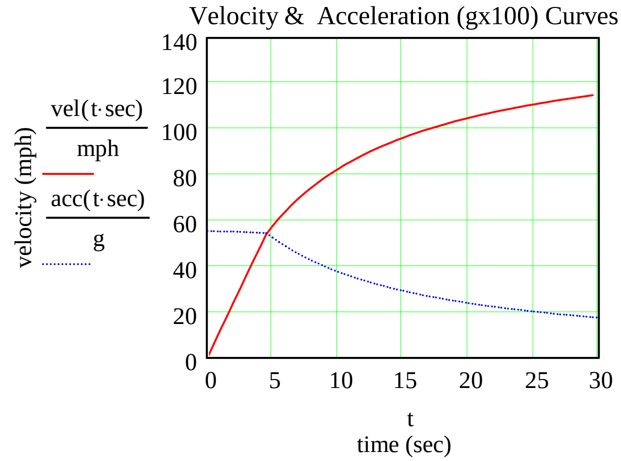
$V := 0 \cdot mph$ $\quad vel(t) := root\left(V - \int_0^t a(V) \cdot \tau \, dt, V\right)$ $\quad vel(60 \cdot sec) = 127.59 \, mph$

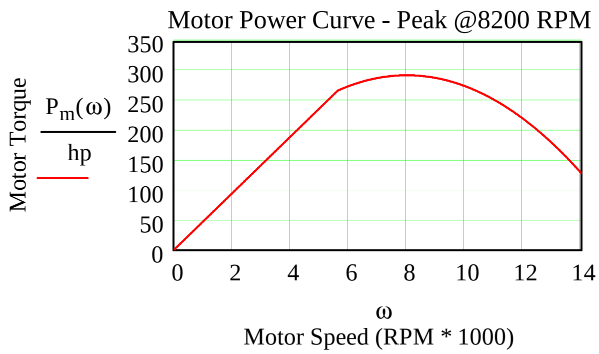
Acceleration in g ›. _ _ _ $\quad acc(t) := a(vel(t \cdot sec)) \cdot 100$

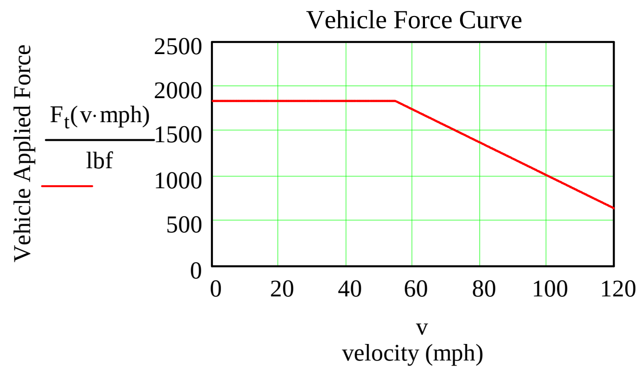
$Time := 0 \cdot sec$ $\quad time(v) := root(v - vel(Time), Time)$ $\quad time(60 \cdot mph) = 5.337 \, s$

ESTIMATED PEFORMANCE CURVES









Find the Single Charge (@SOC = 50%) Cruise Range for a given Velocity

Driving Pattern/Profile:

Assume we cruise at constant speed and start, stop, and regen breaking every 15 minutes.

Drive Train Power Efficiency - Battery Loss to Force Commanded Vehicle Velocity:

State of Charge for generator is SOC_{gen}. **SOC_{gen} is 50% for recharge.** 320V HV battery idle power is Po. 12V battery gives Accessory Power. The Traction Inverter Efficiency - TInvE, HV Power Electronics at Idle Efficiency - IPEE, and Gear Power Efficiency - GPE are 92.5%, 95%, and 90%, respectively. Brake Regen efficiency of kinetic energy is 70%. Then the number of starts per hour as a function of velocity, NS, NumStarts(v, Po), is

$W4DE := 0.94$ $\quad TInvE := 0.925$ $\quad IPEE := 0.95$ $\quad GPE := 0.9$ $\quad Regen := 0.7$ $\quad v := 0, 2 .. 80$ $\quad SOC_{gen} := 0.5$

$$Power_{dissLoss}(v, P_o) := \frac{Fo(v) \cdot v}{TInvE \cdot GPE \cdot W4DE} + \frac{P_o \cdot watt}{IPEE}$$

USABC Round Trip Battery Energy Efficiency

$RTEff := 0.92$

$Energy_{accel}(v) := Power_{max} \cdot time(v)$

NSo and NS are iterative converging estimates of NumStarts

$$NS_o(v) := 2 \cdot \left(\frac{50 \cdot mph}{v}\right)^2$$

$$NS(v, P_o, S) := \frac{Energy_{bat} \cdot (1 - S) - NS_o(v) \cdot \left(\frac{Energy_{accel}(v)}{TInvE \cdot GPE \cdot W4DE} - \frac{Regen \cdot M_{gross} \cdot v^2}{2}\right)}{Power_{dissLoss}(v, P_o) \cdot 15 \cdot min}$$

$$NumStarts(v, P_o, S) := floor\left[\frac{Energy_{bat} \cdot (1 - S) - NS(v, P_o, S) \cdot \left(\frac{Energy_{accel}(v)}{TInvE \cdot GPE \cdot W4DE} - \frac{Regen \cdot M_{gross} \cdot v^2}{2}\right)}{Power_{dissLoss}(v, P_o) \cdot 15 \cdot min}\right]$$

$$Cruise\_Range(v, P_o, S) := \frac{\left[Energy_{bat} \cdot (1 - S) - NumStarts(v, P_o, S) \cdot \left(\frac{Energy_{accel}(v)}{TInvE \cdot GPE \cdot W4DE} - \frac{Regen \cdot M_{gross} \cdot v^2}{2}\right)\right] \cdot v}{Power_{dissLoss}(v, P_o)}$$

Single Charge Highway Cruise Range Estimate

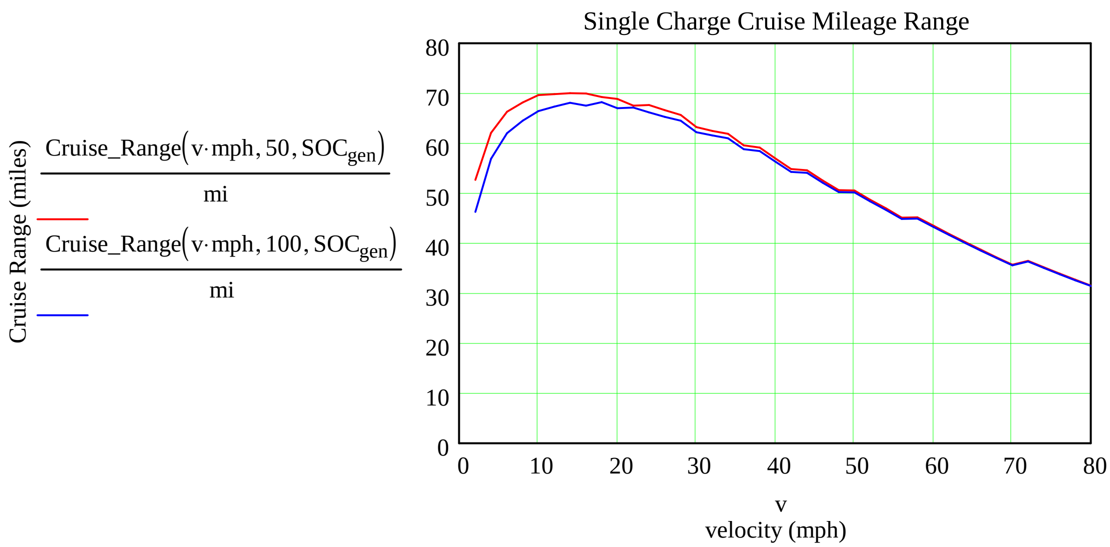
$$\text{Cruise\_Range}\left(30\cdot\text{mph}, 50, \text{SOC}_{gen}\right) = 63.21\,\text{mi}$$

$$\text{Cruise\_Range}\left(40\cdot\text{mph}, 50, \text{SOC}_{gen}\right) = 56.913\,\text{mi}$$

$$\text{Cruise\_Range}\left(50\cdot\text{mph}, 50, \text{SOC}_{gen}\right) = 50.521\,\text{mi}$$

$$\text{Cruise\_Range}\left(60\cdot\text{mph}, 50, \text{SOC}_{gen}\right) = 43.465\,\text{mi}$$

$$\text{Cruise\_Range}\left(70\cdot\text{mph}, 50, \text{SOC}_{gen}\right) = 35.705\,\text{mi}$$

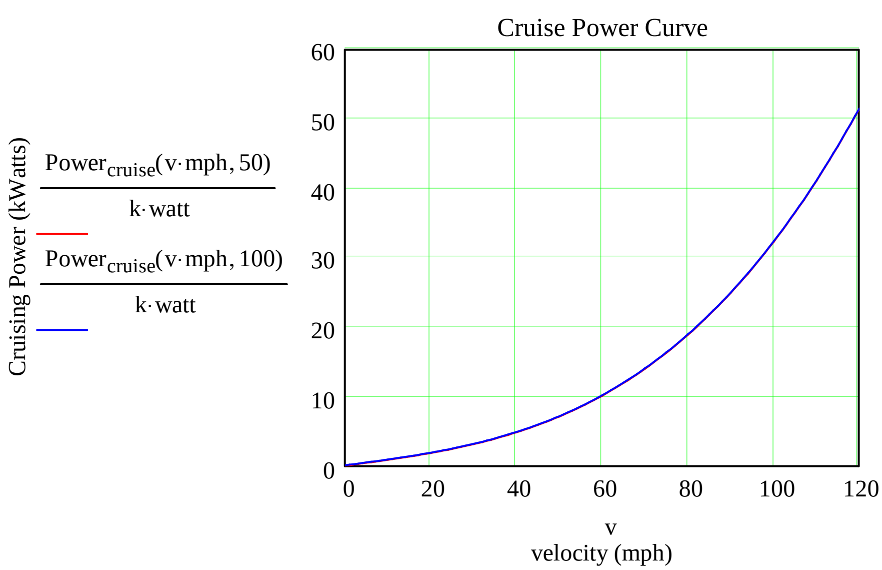


Single Charge "Highway" Cruise Range @70 mph is 150 mph.
Specsmanship: Twice as much range at 30 mph than 70 mph.
Conclusion: I need a bigger or a better battery!

Opposing Force Power Dissipation

$$\text{Power}_{cruise}\left(v, P_o\right) := \text{Power}_{dissLoss}\left(v, P_o\right) \qquad v := 0, 1 .. 120$$

$$\text{Power}_{cruise}(60\cdot\text{mph}, 500) = 1.063\times 10^{4}\ \text{watt}$$



AER Given Three Different Driving Schedules

Read US06 and FTP Driving Profile Files

http://www.epa.gov/nvfel/testing/dynamometer.htm

The US06 cycle represents an 8.01 mile (12.8 km) route with an average speed of 48.4 miles/h (77.9 km/h), maximum speed 80.3 miles/h (129.2 km/h), and a duration of 596 seconds.
The Federal Test Procedure(FTP) is composed of the UDDS followed by the first 505 seconds of the UDDS. It is often called the EPA75. FP10 is a 10 Hz Sampling. HY10 is the 10 Hz Highway schedule.

FTPF := READPRN("http://www.leapcad.com/Transportation/FedTestProc.TXT")

UDDSF := READPRN("http://www.leapcad.com/Transportation/uddscol.txt")

HWYF := READPRN("http://www.leapcad.com/Transportation/hwycol.txt")

FP10 := READPRN("http://www.leapcad.com/Transportation/FTP10Hz.TXT")

HY10 := READPRN("http://www.leapcad.com/Transportation/HWY10Hz.txt")

US06F := READPRN("http://www.leapcad.com/Transportation/US06PROFILE.TXT")

Calculate All Electric Range, AER, for Driving Profile Velocity/Time File, P and Sampling Rate, Hz

Regen Efficiency Curve vs Decel (g): $REff(g) := \frac{85}{77}\cdot 0.01\cdot\left[\left(1 - e^{-27.129\cdot g}\right)\cdot 91.235 - 28.408\right]$ $\quad Gg := \frac{mph}{sec\cdot g}$

AER(P, Hz) :=

$Ebat \leftarrow E_{diss} \leftarrow v_{old} \leftarrow 0$

$n \leftarrow -1$

$N \leftarrow rows(P) - 1$

while $E_{diss} < 8 \wedge n = n$

- $n \leftarrow n + 1$
- $t \leftarrow mod(n, N)$
- $v \leftarrow P_t$
- $v_{avg} \leftarrow (v + v_{old})\cdot 0.5$
- $P_{accel} \leftarrow \dfrac{k_m\cdot M_{gross}\cdot(v - v_{old})\cdot\frac{mph\cdot Hz}{sec}\cdot v_{avg}\,mph}{TInvE\cdot GPE}$ if $v > v_{old}$
- $P_{accel} \leftarrow k_m\cdot M_{gross}\cdot(v - v_{old})\cdot\frac{mph\cdot Hz}{sec}\cdot v_{avg}\,mph\cdot REff\left[(v_{old} - v)\cdot Hz\cdot Gg\right]$ otherwise
- $E_{diss} \leftarrow E_{diss} + \dfrac{\left(Power_{dissLoss}(v\cdot mph, 100) + P_{accel}\right)\cdot sec}{kW\cdot hr\cdot Hz}$
- $v_{old} \leftarrow v$
- $Ebat_n \leftarrow E_{diss}$

$R \leftarrow \sum_{m=0}^{n}\dfrac{\left(P_{mod(m,N)} + P_{mod(m+1,N)}\right)\cdot mph\cdot sec}{2\cdot mi\cdot Hz}$

R

$t := FTPF^{\langle 0\rangle}$ $\quad FTP := FTPF^{\langle 1\rangle}$ $\quad UDDS := UDDSF^{\langle 1\rangle}$

$HWY := HWYF^{\langle 1\rangle}$ $\quad R_{hwy} := rows(HWY)$

$r1 := 0..rows(HY10)\cdot 10 - 1$ $\quad time := US06F^{\langle 0\rangle}$ $\quad US06 := US06F^{\langle 1\rangle}$ $\quad n_6 := 0..598$

$HWY10V := \text{submatrix}(HY10, 0, \text{rows}(HY10) - 1, 1, \text{cols}(HY10) - 1)$ $HWY10_{r1} := HWY10V_{\text{ceil}\left(\frac{r1+1}{10}\right)-1,\ \text{mod}(r1,10)}$

$FTP10V := \text{submatrix}(FP10, 0, \text{rows}(FP10) - 1, 1, \text{cols}(FP10) - 1)$

$AER(US06, 1) = ▪$ $AER(FTP, 1) = 40.183$ $AER(HWY, 1) = 41.96$ $AER(HWY10, 10) = ▪$

EPA 20085 Cycle MPG Fuel Economy Least Squares Fit Regression for AER

$$MPG_{city} := \frac{1}{\left(0.003259 + \frac{1.18053}{AER(FTP,1)}\right)} \quad MPG_{city} = 30.639 \quad MPG_{hwy} := \frac{1}{0.001376 + \frac{1.3466}{AER(HWY,1)}} \quad X := \frac{1}{40}$$

$MPG_{epa} := 0.55 \cdot MPG_{city} + 0.45 \cdot MPG_{hwy}$ $MPG_{epa} = 30.297$

$r := 0 .. \text{rows}(FTP) - 1$ $Distance_r := \sum_{r=0}^{r} FTP_r \cdot \frac{10}{60 \cdot 60}$ $rr := 0 .. \text{rows}(US06) - 1$ $Distance._{rr} := \sum_{rr=0}^{rr} US06_{rr} \cdot \frac{10}{60 \cdot 60}$

$\max(Distance) = 110.414$ $\max(Distance.) = 80.08$

$WRITEPRN(\text{"EFTP.PRN"}) := AER(FTP, 1) \cdot 40$ $E_{FTP} := READPRN(\text{"EFTP.PRN"})$ $\max(E_{FTP}) \cdot X = 37.125$

$WRITEPRN(\text{"EUS06.PRN"}) := AER(US06, 1) \cdot 40$ $E_{US06} := READPRN(\text{"EUS06.PRN"})$ $\max(E_{US06}) \cdot X = 27.425$

$WRITEPRN(\text{"EHWY.PRN"}) := AER(HWY, 1) \cdot 40$ $E_{HWY} := READPRN(\text{"EHWY.PRN"})$ $\max(E_{HWY}) \cdot X = 39.05$