TESLA EV 1.5 PERFORMANCE SIMULATION

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

VXPhysics.com

Tesla - Vehicle, Motor, Road, and Environmental Parameters: ***Fixed Gears:*** **6,000,8000 RPM Pk Power**

Max Motor Power: $Power_{max1} := 185 \cdot kW$

Fixed Two Gear Ratios: $GR_1 := 14.3 \quad GR_2 := 7.4$

Max Motor Torque: $T_{max} := 210 \cdot ft \cdot lbf$

Power Train 1.5: $Power_{max} := 0.77 \cdot 850 \cdot 370 \cdot W$

Battery Energy: $Energy_{bat} := 53 \cdot kW \cdot hr$

Max Motor Torque: $T_{max} := 280 \cdot ft \cdot lbf$

Tire Radius*: $r_{tire} := \frac{78.45}{2 \cdot \pi} \cdot in$

$GR_{1.5} := 8.2752 \cdot 1.124$

Max Force, FMaxTire $Fm_{tire1} := GR_1 \cdot \frac{T_{max}}{r_{tire}}$ $\quad Fm_{tire2} := GR_2 \cdot \frac{T_{max}}{r_{tire}}$ $\quad Fm_{tire1.5} := GR_{1.5} \cdot \frac{T_{max}}{r_{tire}}$

$RPM := min^{-1}$

Max Power, ω: $\omega_{Pmax} := \frac{Power_{max}}{T_{max}}$ $\quad RPM_{Pmax} := \frac{\omega_{Pmax}}{2 \cdot \pi}$ $\quad RPM_{Pmax} = 6.091 \times 10^3 \, RPM$

Constant Power vehicle velocity, v_{CP}: $v_{CP} := \frac{Power_{max}}{Fm_{tire1.5}}$ $\quad v_{CP} = 48.653 \, mph$ $\quad Power_{max} = 324.749 \, hp$

Lotus Elsie Chassis Curb Weight: $k := 10^3$ $\quad M_{curb} := 1350 \cdot kg$ $\quad M_{curb} := 2733 \cdot lb$

Time, in seconds: $t := 0, 0.5 .. 30$

Time unit: $\tau := 1 \cdot sec$

Average Wind Velocity: $Vw := 0 \cdot mph \quad V_{cw} := 0 \cdot mpl$

Shape Correction Factor: $SCF := 0.85$

Frontal Area*: $Afg := 1.127 \cdot m \cdot 1.7 \cdot m$

Drag Coeff: $Cd := 0.3$

Frontal Area $Af := Afg \cdot SCF \quad Af = 1.629 \, m^2$

Cross Wind Drag Coff: $Cd_{cw} := 0.000014$

Tire Rolling Resist, Hys: $RR_{tire} := 0.007 \quad T_{hys} := 0 \cdot \frac{sec}{m}$

Air Density: $\rho := 1.293 \cdot \frac{gm}{liter}$

θ (radians): $\theta := atan(0.0)$

Road Rolling Resist: $RR_{road} := 0.002$

Drive Train Drag Coeff: $Cdt := 0.024 \cdot \frac{N}{mph^2}$

Gross Weight: $M_{batt} := 1000 lb$

$Passengers2 := 170 \cdot lb$ $\quad F_{static} := 1 \cdot N$

$M_{gross} := M_{curb} + Passengers2$

Rotational Inertia Coeff: $k_m := 1.08$

$M_{gross} = 2.903 \times 10^3 \, lb$

Vehicle Dynamics Equations:

Velocity at Torque Fall: $v_{T1} := 6100 \cdot RPM \cdot 2 \cdot \pi \cdot r_{tire} \cdot GR_1^{-1}$ $\quad v_{T1} = 31.69 \, mph$

Velocity to RPM: $VtoR(v) := v \cdot \left(k \cdot 2 \cdot \pi \cdot r_{tire} \cdot RPM\right)^{-1}$ $\quad VtoR(61 \cdot mph) \cdot GR_2 = 6.076$

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

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

$\omega_{fall} := 6 \cdot RPM$

Opposing Force, Fo: $Fo(v) := Fa(v) + Ft(v)$ $\quad Fo(60 \cdot mph) = 430.855 \, N$

$\omega_{fall} := RPM_{Pmax} \cdot k^{-}$

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

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

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

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

Third Law of Motion:
(a is acceleration) $a(v) := \frac{F_t(v) - Fo(v)}{k_m \cdot M_{gross}}$ $\quad Power_{max} := P_m(8)$ $\quad Power_{max} = 344.346 \, hp$

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

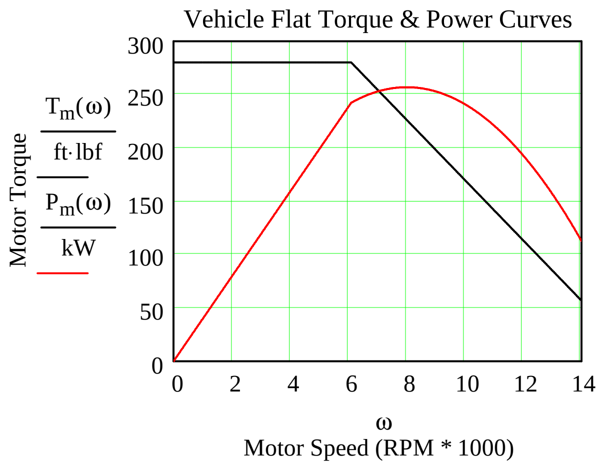
$End := 20$ $\quad$ Given $\quad \frac{d}{dt} v(t) = a(v(t))$ $\quad v(0) = 0$ $\quad vel := Odesolve(t, End)$

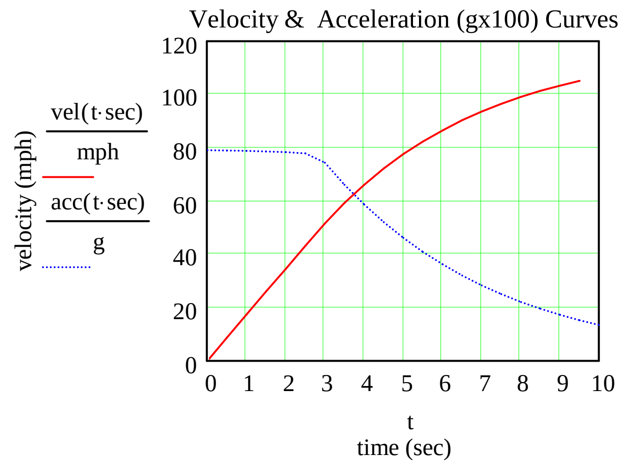
Acceleration in g x 100 $\quad acc(t) := a(vel(t \cdot sec)) \cdot 100$ $\quad$ **Roadster Spec is 3.7 sec**

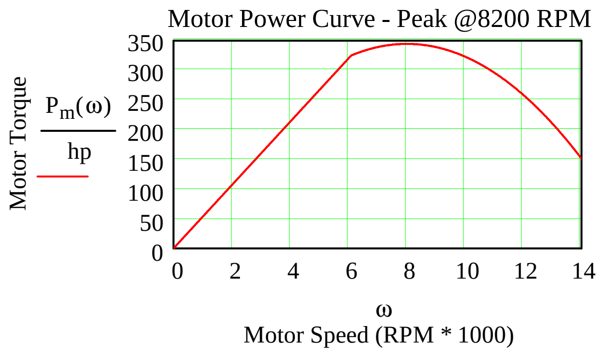
$Time := 0 \cdot sec$ $\quad time(v) := root(v - vel(Time), Time)$ $\quad time(60 \cdot mph) = 3.551 \, s$

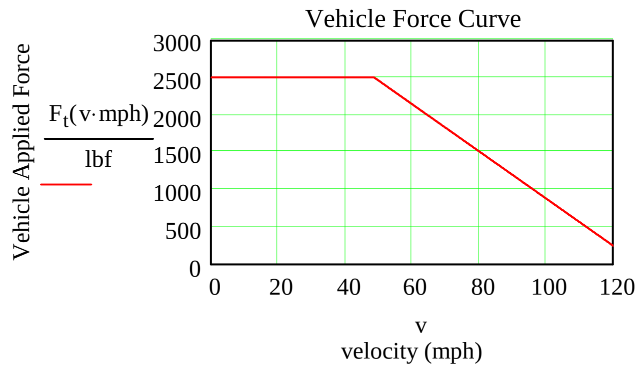
TESLA MOTORS ESTIMATED PEFORMANCE CURVES: Power Train 1.5

Compare with Torque & PowerCurves at: http://www.teslamotors.com/performance/acceleration_and_torque.php









Find the Single Charge (@SOC = 20%) 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 20% for recharge.** 320V HV battery idle power is Po. 12V battery gives Accessory Power. Gear Efficiencies are modeled dynamically with Drive Train Drag Coefficient Cdt. 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

$$IPEE := 0.95 \qquad Regen := 0.7 \qquad v := 0, 2 .. 80 \qquad SOC_{gen} := 0.2$$

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

NSo and NS are iterative converging estimates of NumStarts

USABC Round Trip Battery Energy Efficiency

$$RTEff := 0.92$$

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

$$NS_o(v) := 2 \cdot \left(\frac{50 \cdot mph}{v}\right)^2 \qquad NS(v, P_o, S) := \frac{Energy_{bat} \cdot (1 - S) - NS_o(v) \cdot \left(Energy_{accel}(v) - \frac{Regen \cdot M_{gross} \cdot v^2}{2}\right)}{Power_{dissLoss}(v, P_o) \cdot 15 \cdot min}$$

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

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

Single Charge Highway Cruise Range Estimate

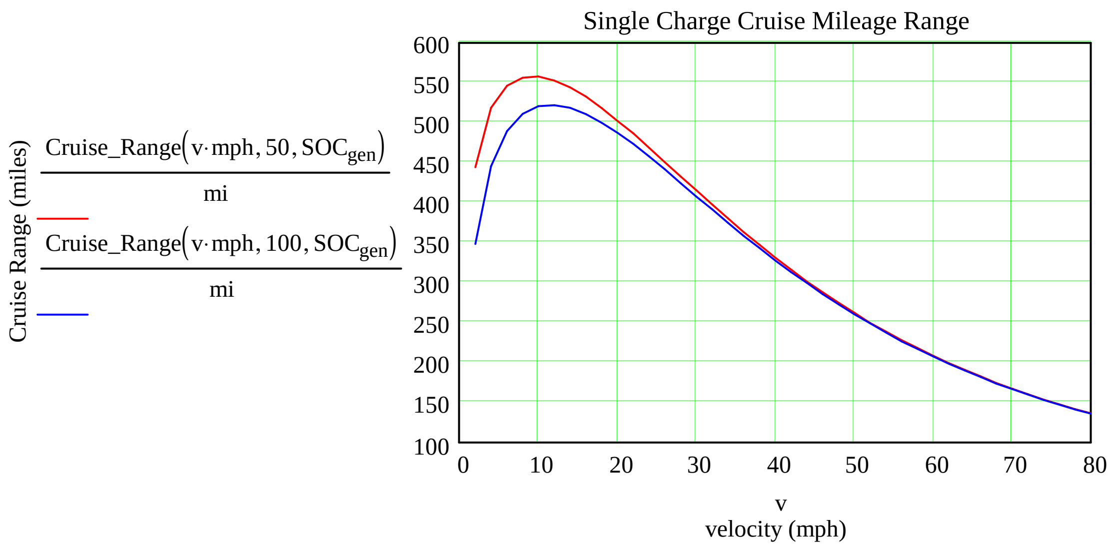
$$\text{Cruise\_Range}(30\cdot mph, 50, SOC_{gen}) = 415.439\ mi$$

$$\text{Cruise\_Range}(40\cdot mph, 50, SOC_{gen}) = 331.109\ mi$$

$$\text{Cruise\_Range}(50\cdot mph, 50, SOC_{gen}) = 262.131\ mi$$

$$\text{Cruise\_Range}(60\cdot mph, 50, SOC_{gen}) = 208.307\ mi$$

$$\text{Cruise\_Range}(70\cdot mph, 50, SOC_{gen}) = 167.048\ mi$$

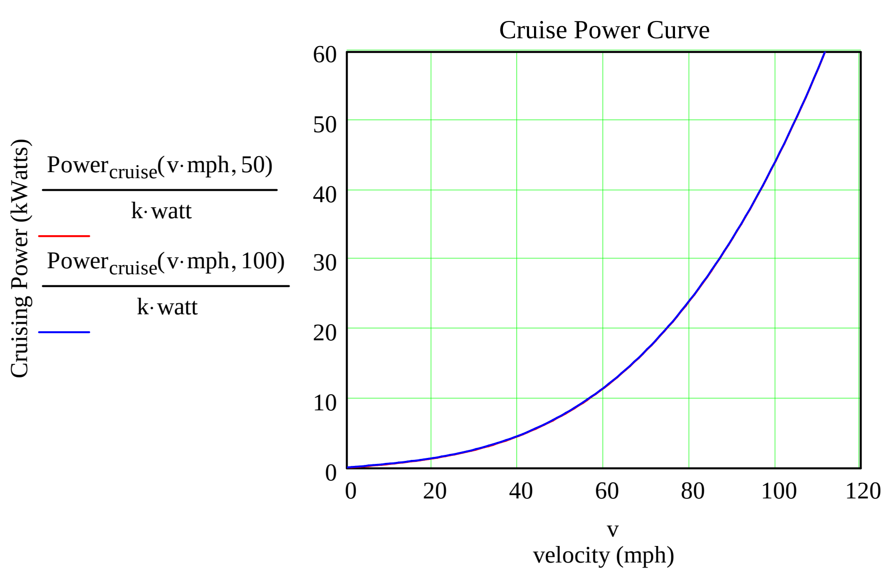


Single Charge "Highway" Cruise Range @70 mph is 150 mph.
Specsmanship: Twice as much range at 30 mph than 70 mph.
Conclusion: I need a bigger or a better battery!

Opposing Force Power Dissipation

$$Power_{cruise}(v, P_o) := Power_{dissLoss}(v, P_o) \qquad v := 0, 1 .. 120$$

$$Power_{cruise}(60\cdot mph, 500) = 1.208 \times 10^4\ watt$$



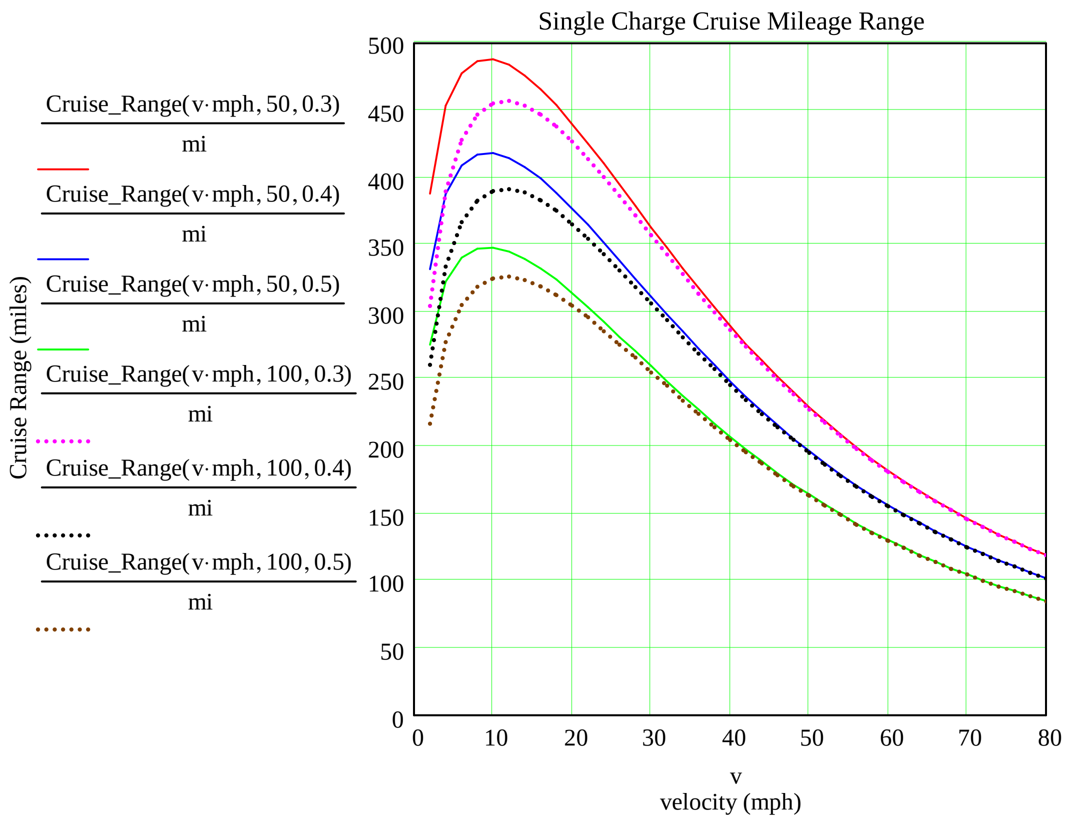
$v := 0, 2 .. 80$

$\text{Cruise\_Range}(55 \cdot \text{mph}, 100, 0.3) = 203.174\,\text{mi}$

$\text{Cruise\_Range}(55 \cdot \text{mph}, 100, 0.5) = 145.124\,\text{mi}$

$\frac{0.5 - 0.25}{0.5} = 0.5$

$\frac{\text{Cruise\_Range}(55 \cdot \text{mph}, 100, 0.25) - \text{Cruise\_Range}(55 \cdot \text{mph}, 100, 0.5)}{\text{Cruise\_Range}(55 \cdot \text{mph}, 100, 0.5)} = 0.5$



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")

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. HWY is the Highway schedule.

$$t := FTPF^{\langle 0\rangle} \qquad FTP := FTPF^{\langle 1\rangle} \qquad rows(FTP) = 1.875\times 10^{3}$$

$$UDDS := UDDSF^{\langle 1\rangle} \quad rows(UDDS) = 1.37\times 10^{3}$$

$$FP := FP10 \qquad HWY := HWYF^{\langle 1\rangle} \quad rows(HWY) = 766$$

$$FTP10 := stack\left(FP^{\langle 1\rangle}, FP^{\langle 2\rangle}, FP^{\langle 3\rangle}, FP^{\langle 4\rangle}, FP^{\langle 5\rangle}, FP^{\langle 6\rangle}, FP^{\langle 7\rangle}, FP^{\langle 8\rangle}, FP^{\langle 9\rangle}, FP^{\langle 10\rangle}\right.$$

$$time := US06F^{\langle 0\rangle} \qquad US06 := US06F^{\langle 1\rangle} \qquad n := 0..598$$

$$FTP10V := submatrix(FP10, 0, rows(FP10) - 1, 1, cols(FP10) - 1)$$

$$HWY10V := submatrix(HY10, 0, rows(HY10) - 1, 1, cols(HY10) - 1)$$

Calculate All Electric Range, AER, for Driving Profile File, P, SOC = 20%

$$
\begin{array}{l}
AER(P) := \\
\quad E_{diss} \leftarrow 0 \\
\quad v_{old} \leftarrow 0 \\
\quad n \leftarrow -1 \\
\quad N \leftarrow rows(P) - 1 \\
\quad \text{while } E_{diss} < \dfrac{Energy_{bat}}{kW\cdot hr}\cdot\left(1 - SOC_{gen}\right) \\
\qquad n \leftarrow n + 1 \\
\qquad t \leftarrow mod(n, N) \\
\qquad v \leftarrow P_{t} \\
\qquad v_{avg} \leftarrow \left(v + v_{old}\right)\cdot 0.5 \\
\qquad P_{accel} \leftarrow k_{m}\cdot M_{gross}\cdot\left(v - v_{old}\right)\cdot\dfrac{mph}{sec}\cdot v_{avg}\, mph \quad \text{if } v > v_{old} \\
\qquad P_{accel} \leftarrow k_{m}\cdot M_{gross}\cdot\left(v - v_{old}\right)\cdot\dfrac{mph}{sec}\cdot v_{avg}\, mph\cdot Regen \quad \text{otherwise} \\
\qquad E_{diss} \leftarrow E_{diss} + \dfrac{\left(Power_{dissLoss}(v\cdot mph, 100) + P_{accel}\right)\cdot sec}{kW\cdot hr} \\
\qquad v_{old} \leftarrow v \\
\quad R \leftarrow \displaystyle\sum_{m=0}^{n} \dfrac{P_{mod(m,N)}\cdot mph\cdot sec}{mi}
\end{array}
$$

$$r1 := 0..rows(HY10)\cdot 10 - 1 \qquad HWY10_{r1} := HWY10V_{ceil\left(\frac{r1+1}{10}\right)-1,\, mod(r1, 10)}$$

$$AER(US06) = 172.598 \qquad AER(FTP) = 301.319 \qquad AER(FTP10) = 302.511 \qquad AER(HWY) = 250.838$$

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

$AER(FTP) = 301.319 \qquad AER(HWY) = 250.838$

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

$$MPG_{city} := \frac{1}{\left(0.003259 + \frac{1.18053}{AER(FTP)}\right)} \qquad MPG_{city} = 139.336 \qquad MPG_{hwy} := \frac{1}{0.001376 + \frac{1.3466}{AER(HWY)}} \qquad X := \frac{1}{40}$$

$MPG_{epa} := 0.55\cdot MPG_{city} + 0.45\cdot MPG_{hwy} \qquad MPG_{epa} = 143.357$

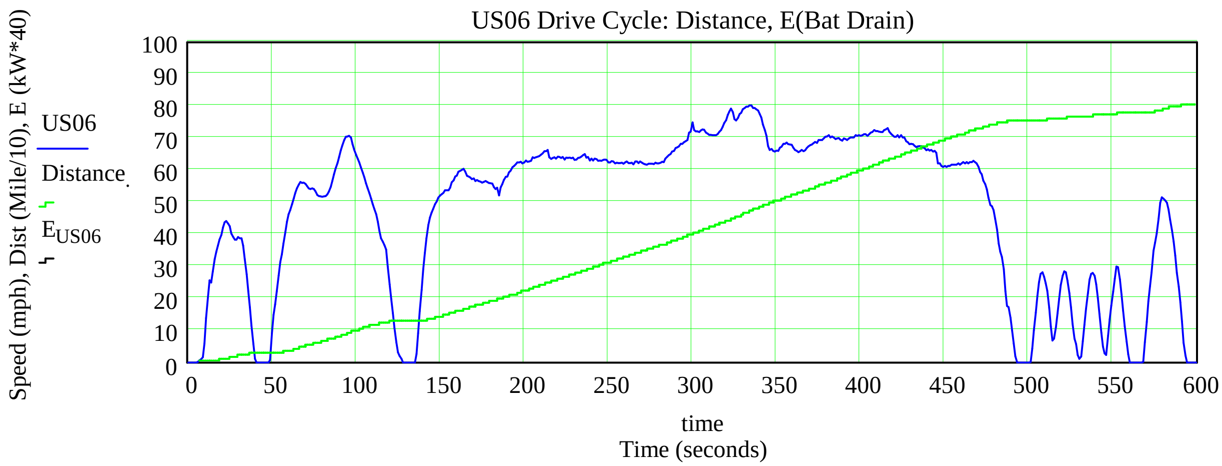
$r := 0..\text{rows}(FTP) - 1 \qquad Distance_r := \sum_{r=0}^{r} FTP_r \cdot \frac{10}{60\cdot 60} \qquad rr := 0..\text{rows}(US06) - 1 \quad Distance_{.rr} := \sum_{rr=0}^{rr} US06_{rr}\cdot\frac{10}{60\cdot 60}$

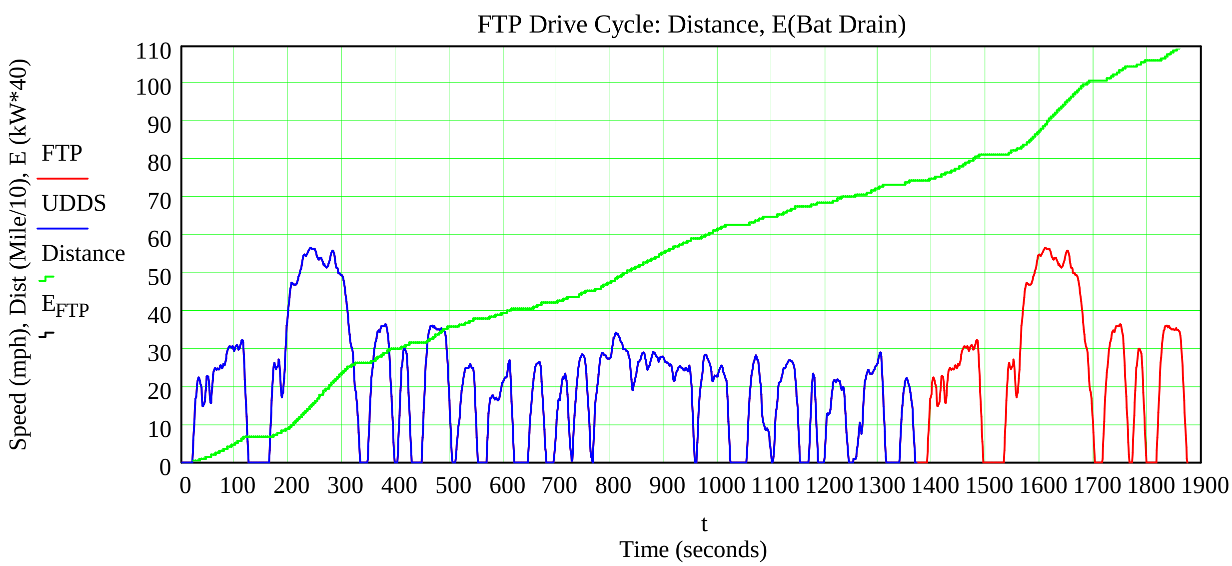
$\max(Distance) = 110.414 \qquad \max(Distance_.) = 80.08$

$WRITEPRN("EFTP.PRN") := AER(FTP)\cdot 40 \qquad E_{FTP} := READPRN("EFTP.PRN") \qquad \max(E_{FTP})\cdot X = 301.25$

$WRITEPRN("EUS06.PRN") := AER(US06)\cdot 40 \qquad E_{US06} := READPRN("EUS06.PRN") \qquad \max(E_{US06})\cdot X = 172.6$

$WRITEPRN("EHWY.PRN") := AER(HWY)\cdot 40 \qquad E_{HWY} := READPRN("EHWY.PRN") \qquad \max(E_{HWY})\cdot X = 250.75$





Read Tesla Roadster 1.5 Computer Model Loss Data from File:

Data in Eight Columns:

Speed	Total	Ancillary	Tires	Aero	Drivetrain	Range	Power
mph	Wh/mi	Wh/mi	Wh/mi	Wh/mi	Wh/mi	mi	kW

TL := READPRN("http://www.leapcad.com/Transportation/Tesla%20Losses.TXT") $W\cdot\frac{hr}{mi} = 2.237\,N$

$Speed := TL^{\langle 0\rangle}$ $PwrTesla := TL^{\langle 7\rangle}$ $Speed_{39} = 80$ $Speed_{26} = 54$ $Speed_0 = 2$

$TV := \overrightarrow{\left(\frac{Speed\cdot TL^{\langle 1\rangle}}{1000}\right)}$ $Tires := \overrightarrow{\left(\frac{Speed\cdot TL^{\langle 3\rangle}}{1000}\right)}$ $Aero := \overrightarrow{\left(\frac{Speed\cdot TL^{\langle 4\rangle}}{1000}\right)}$ $DT := \overrightarrow{\frac{Speed\cdot TL^{\langle 5\rangle}}{1000}}$

$All := \overrightarrow{(Tires + Aero + DT)}$ $v := 0, 1 .. 100$ $PwrTesla_0 = 0.7$

Model the Drive Train Losses, DTmodel, as Square of Velocity
Assume 300 W of Accessory Power

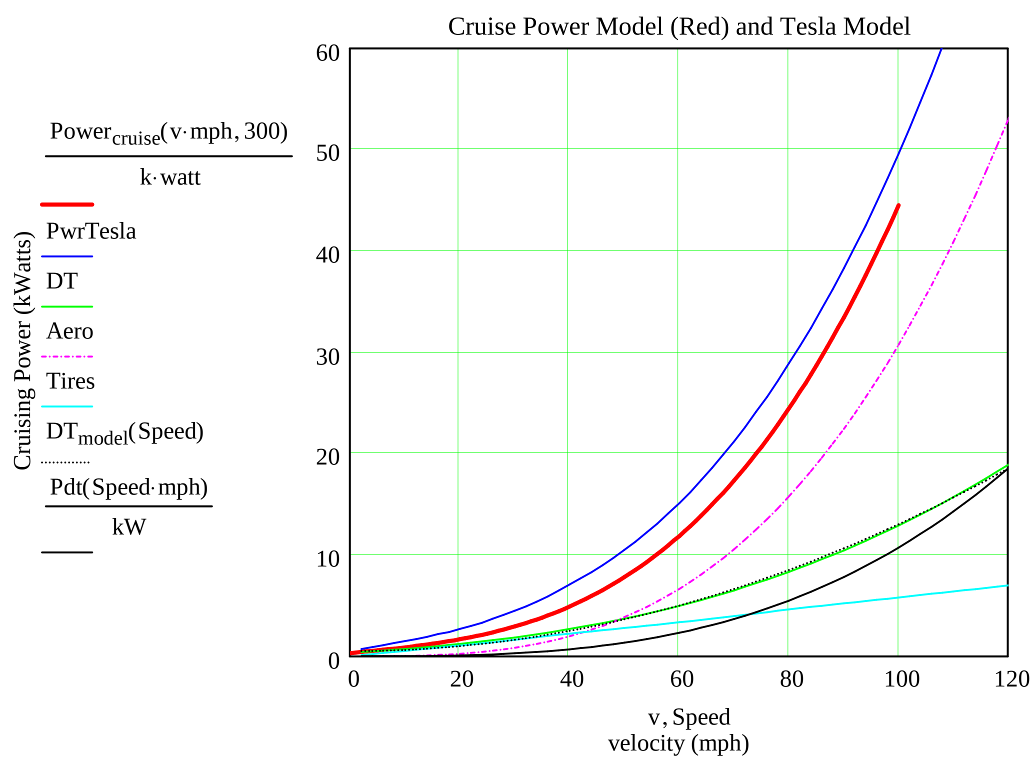
$guess := \begin{pmatrix} 0.1 \\ 0.001 \end{pmatrix}$ $F(n, a) := \begin{pmatrix} a_0 + a_1\cdot n^2 \\ n \\ n^2 \end{pmatrix}$ $G := genfit(Speed, DT, guess, F)$ $G = \begin{pmatrix} 0.501 \\ 1.253\times 10^{-3} \end{pmatrix}$

Static Force Term

$DT_{model}(v) := G_0 + G_1\cdot v^2$ $Pdt(v) := 0.024\cdot\frac{N}{mph^2}\cdot v^3$

$.5\cdot\frac{W\cdot hr}{mi} = 1.118\,N$ $G_1\cdot\frac{W\cdot hr}{mi\cdot mph^2} = 2.804\times 10^{-3}\,\frac{N}{mph^2}$

$DT_{mod} := 0.5\cdot N + G_1\cdot\frac{N}{mph^2}\cdot(60\cdot mph)^2$ $DT_{mod} = 5.012\,N$



Find Residual Error Between Cruise Power Force at 54 mph and Tesla's Power
Assign Error to Drive Train Drag Coefficient, Cdt. Cruise Drive Train Drag Force = Cdt * v^2

$$\text{PowerErrorFactor} := \frac{\text{All}_{26} - \dfrac{\text{Power}_{\text{cruise}}(54\cdot\text{mph}, 300)}{\text{k}\cdot\text{watt}}}{(54)^2}$$

$$\text{Cdt} := \text{PowerErrorFactor}\cdot\frac{1000\cdot\text{m}}{54\text{mph}\cdot\text{s}}$$

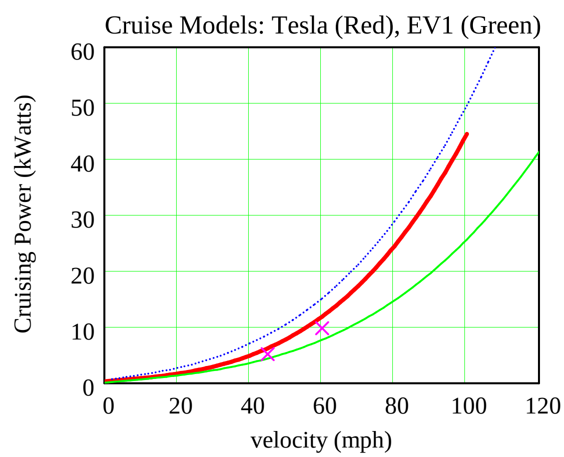
$\text{Cdt} = 0.039$

Use this in First Page, Drive Train Coefficient: Cdt = 0.024 @54mph, 0.026 @80,

$\text{PowerErrorFactor} = 9.515\times 10^{-4}$ Power Error Factor = 0.000923

Plot EV1 and Tesla Cruise Power Data on same Plot

$\text{EVDat} := \text{READPRN("EV1Cpwr.txt")}$ $\text{PWR} := \text{EVDat}^{\langle 1\rangle}$ $\text{Spd} := \begin{pmatrix} 45 \\ 60 \end{pmatrix}$ $\text{Pwr} := \begin{pmatrix} 5.19 \\ 9.79 \end{pmatrix}$



Petroleum-equivalent efficiency
See also: Electric car: Comparison with internal combustion vehicles (ICEVs)

The Roadster does not actually use gasoline; therefore, petroleum-equivalent efficiency (mpg, l/100 km) cannot be measured directly but instead is calculated using one of several different methods:

A number comparable to the typical Monroney sticker's "pump-to-wheel" fuel efficiency can be calculated based on regulations from the DOE and its energy content for a U.S. gallon of gasoline of 33,705 W·h/gal (also called the Lower Heating Value (LHV) of gasoline)

$$\frac{33705\,\frac{\text{W·h}}{\text{gal}_{\text{ge}}}}{135\,\frac{\text{W·h}}{\text{km}}\times\frac{1.6\,\text{km}}{\text{mi}}}\times 77.6\%_{\text{charging eff.}} = 120\,\text{mpg}_{\text{ge}} = 1.95\,\frac{\text{L}_{\text{ge}}}{100\,\text{km}}$$