TOYOTA COROLLA PERFORMANCE SIMULATION

http://www.leapcad.com/Transportation/Corolla_Simulation.mcd VXPhysics.com

Macro Model of Corolla Performance

Procedure:
First model the Internal Combustion Engine's (ICE) torque and power. Define vehicle and road parameters.

Acceleration Protocol:
Assume engine is always on. Start out with torque from 1400 rpm clutch idle speed. Select transmission shift points for maximum acceleration.
Use equations for vehicle dynamics to calculate the time to 60 mph. Plot performance simulation curves. Calculate Calculate MPG using various EPA driving modes.

ICE Performance Curves
Engine torque and power curves base on "flat" torque curves in shown at http://en.wikipedia.org/wiki/Toyota_ZZ_engine#1ZZ.
Specs:
Horsepower (SAE) 130 HP @ 5600
Torque (SAE) 125 lb/ft @ 4400

$130\cdot hp = 96.941\,kW \qquad 125\cdot ft\cdot lbf = 169.477\,N\cdot m$

Torque and Power Simulation:

$E2M := \frac{kW}{hp} \qquad RPM := min^{-1} \qquad k := 1000$

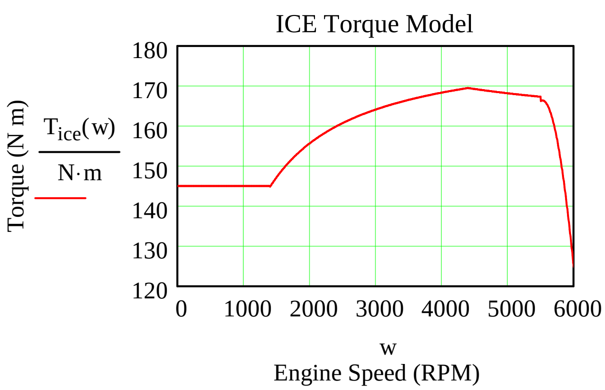
$T_{idle} := 135\cdot E2M \quad T_{peak} := 169\cdot E2M \quad \Omega_{idle} := 1100 \quad \Omega_{idlex} := 1400 \quad \Omega_{Tpk} := 4400 \quad P_{idle} := T_{idle}\cdot\left(\frac{2\cdot\pi\cdot\Omega_{idle}}{60\cdot k}\right)$

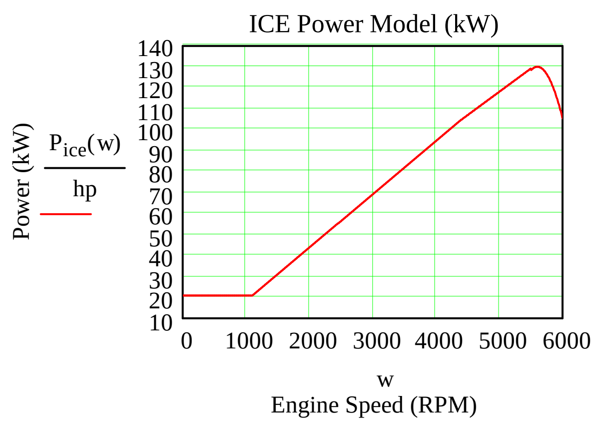
$P_{Tpk} := \frac{169.5\cdot N\cdot m\cdot 2\cdot\pi\cdot 4400\cdot RPM}{hp} \quad P_{Tpkslope} := \frac{P_{Tpk} - P_{idle}}{4400 - \Omega_{idle}} \quad P_{pkslope} := \frac{127 - P_{Tpk}}{5400 - \Omega_{Tpk}}$

$P1_{ice}(w) := if\left[w < \Omega_{idle}, P_{idle}, P_{idle} + P_{Tpkslope}\cdot\left(w - \Omega_{idle}\right)\right] \quad P2a_{ice}(w) := P_{Tpk} + P_{pkslope}\cdot(w - 4400)$

$P2_{ice}(w) := if\left(w < \Omega_{Tpk}, P1_{ice}(w), P2a_{ice}(w)\right) \quad P_{fall}(rpm) := 130\cdot\sin\left(\pi\cdot\frac{rpm - 4600}{2000}\right)$

$P_{ice}(w) := if\left(w < 5500, P2_{ice}(w), P_{fall}(w)\right)\cdot hp \quad T_{ice}(w) := if\left[w < \Omega_{idlex}, 145\cdot N\cdot m, P_{ice}(w)\cdot\frac{1}{2\cdot\pi\cdot(w+1)\cdot RPM}\right]$





Toyota Corolla-Vehicle, Motor and Road Parameters:

Gear Ratio and Efficiencies: $GR_{diff} := 3.421$ $GR_1 := 2.810 \cdot GR_{diff}$ $GR_2 := 1.549 \cdot GR_{diff}$ $GR_3 := 1.000 \cdot GR_{diff}$

$\eta_{diff} := 0.95$ $\eta_{GR} := 0.97$ $\eta_{trans} := 0.95$ $\eta_{drive} := \eta_{diff} \cdot \eta_{GR} \cdot \eta_{trans}$ $\eta_{drive} = 0.875$

Max Motor Power: $Pmax := 130 \cdot hp \cdot \eta_{drive}$ $\Omega max := 6000 \cdot RPM$

Max Motor Torque: $Tmax := 125 ft \cdot lbf \cdot \eta_{drive}$

$r_{tire} := \frac{23.4}{2} \cdot in$ Tire: 185/65R14

Chassis and Environmental Parameters

Average Wind Velocity: $Vw := 0 \cdot mph$

Frontal Area*: $Afg := 2.508 \cdot m^2$

Shape Correction Factor: $SCF := 0.85$

Frontal Area Corrected: $Af := Afg \cdot SCF$ $Af = 2.132\, m^2$

Drag Coeff: $Cd := 0.296$

Rolling Resistance Per Tire: $RR_{tire} := 0.007$

(Average 0% road grade) $\theta := atan(0.0)$ θ (radians):

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

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

Average Cross Wind: $V_{cw} := 0 \cdot mph$

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

Curb Weight: $M_{curb} := 2414 \cdot lb$

Rotational Inertia Coeff: $k_m := 1.08$

Passenger Weight: $Passengers2 := 170 \cdot lb$

Gross Weight: $M_{gross} := M_{curb} + Passengers2$ $M_{gross} = 2.584 \times 10^3\, lb$ $M_{batt} := 68 \cdot kg$

Vehicle Dynamics Equations - Find Velocity and Time for Maximum Acceleration

Road Resistance, Fr: $Fr(v) := M_{gross} \cdot g \cdot \left[\left(RR_{tire} + RR_{road} \right) \cdot \cos(\theta) + \sin(\theta) \right]$ $Fr(60 \cdot mph) = 103.448\, N$

MPGodynamic Loss, Fa: $Fa(v) := 0.5 \cdot \rho \cdot Af \cdot \left[(v + Vw)^2 \cdot Cd + Cd_{cw} \cdot \left(0.5 \cdot v + V_{cw} \right)^2 \right]$ $Fa(60 \cdot mph) = 293.499\, N$

Opposing Force, Fo: $Fo(v) := Fa(v) + Fr(v)$ $Fo(60 \cdot mph) = 396.947\, N$ $Fo(60 \cdot mph) = 396.947\, N$

Automatic Transmission Switch Points: Tweak for Maximum Acceleration Profile

$Tran1(v) := if\left(v < 70 \cdot mph, GR_2, GR_3 \right)$ $Trans(v) := if\left(v < 41 \cdot mph, GR_1, Tran1(v) \right)$

$v\_r(w, GR) := \frac{2 \cdot \pi \cdot r_{tire} \cdot w \cdot RPM}{GR \cdot mph}$ $VtoR(v) := \frac{v \cdot Trans(v)}{2 \cdot \pi \cdot r_{tire} \cdot RPM}$ $F_{tran}(v) := Trans(v) \cdot \frac{T_{ice}(VtoR(v)) \cdot \eta_{drive}}{r_{tire}}$

$P_{icev}(v) := P_{ice}(VtoR(v))$ $T_{icev}(v) := T_{ice}(VtoR(v))$

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

$End := 30$

Third Law of Motion:
(dv/dt is acceleration)

Given $\frac{d}{dt} v(t) = \frac{F_{tran}(v(t)) - Fo(v(t))}{k_m \cdot M_{gross}}$ $v(0) = 0$ $velocity := Odesolve(t, End)$

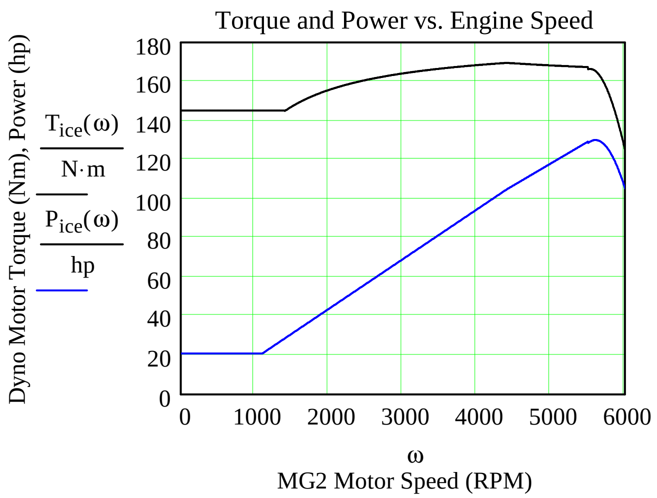
$accel(t) := \frac{F_{tran}(velocity(t)) - Fo(velocity(t))}{k_m \cdot M_{gross}}$

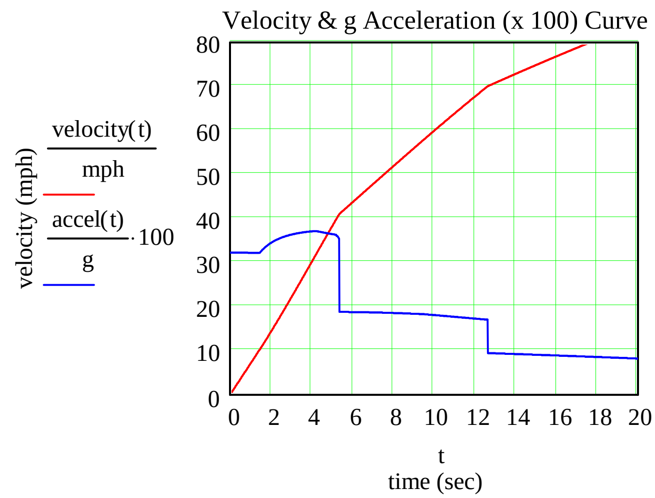
Corolla Spec is 9.3 sec

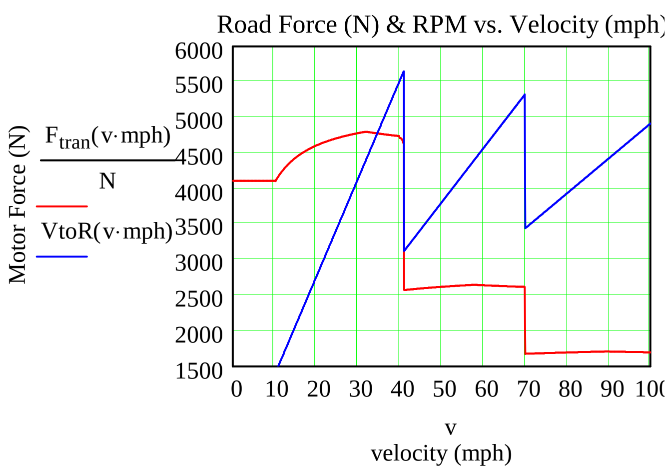
$Time := 0 \cdot sec$ $time(v) := root(v - velocity(Time), Time)$ $time(60 \cdot mph) = 10.019\, s$

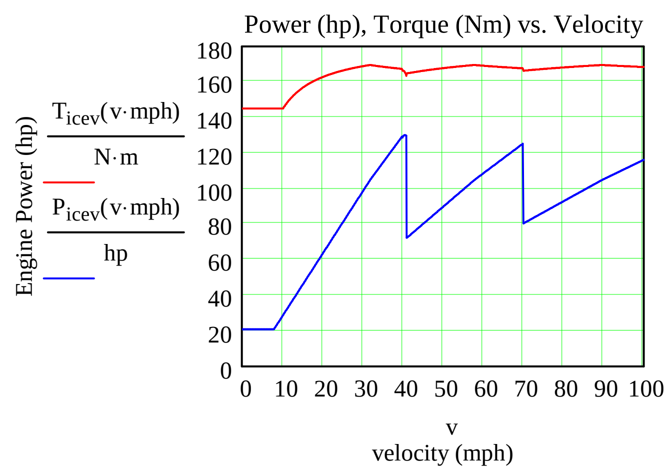
Passing 40 to 60 mph: $Passing := time(60 \cdot mph) - time(40 \cdot mph)$ $Passing = 4.798\, s$

COROLLA PEFORMANCE SIMULATION CURVES









Find the Cruise Power for a given Velocity

Driving Pattern/Profile:

Given we **cruise at constant speed** and Time for start, stop, and regen breaking, **$Time_{ssr}$= every 15 minutes**.

Drive Train Power Efficiency for Commanded Vehicle Velocity:

Idle power is Po. 12V battery gives Accessory Power. Electronics at Idle Efficiency - IPEE, and Gear Power Efficiency - GPE are 90%, 95%, and 97%, respectively. Then the number of starts per hour as a function of velocity, NS, NumStarts(v, Po), is

$Time_{ssr} := 30min \quad TInvE := 0.90 \quad IPEE := 0.95 \quad GPE := 0.97$

$$Power_{dissLoss}(v, P_o) := \frac{Fo(v)\cdot v}{TInvE\cdot GPE} + \frac{P_o\cdot watt}{IPEE} \qquad Energy_{accel}(v) := \frac{P_{icev}(v)}{1}\cdot time(v)$$

Find the Power to Maintain Constant Velocity

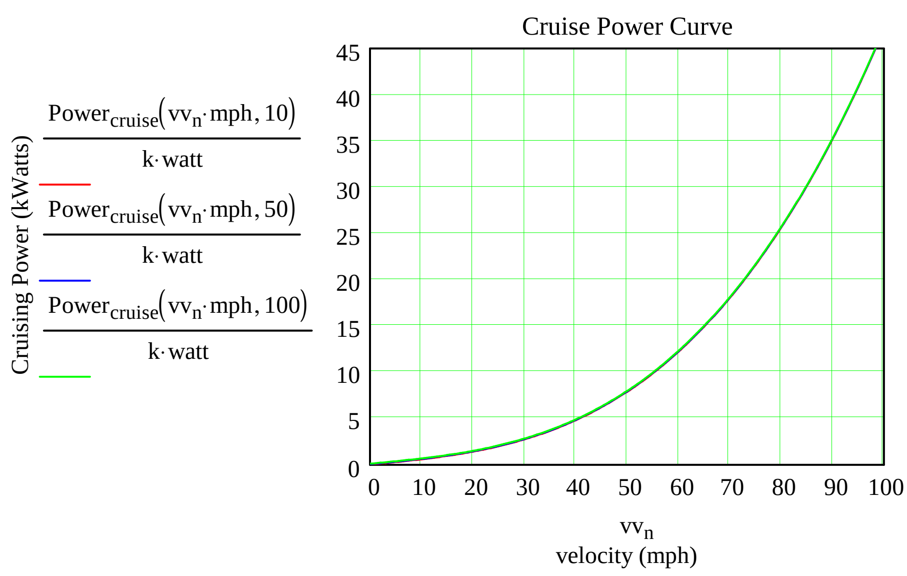
Note: The generator's output is 54 kW. This allows it produce a net charge up to 80 mph cruise.

$$Power_{cruise}(v, P_o) := Power_{dissLoss}(v, P_o)$$

$$Power_{cruise}(60\cdot mph, 100) = 12.301\,kW$$

$$n := 0..200 \quad \tau_n := \frac{n}{10} \quad w_n := \frac{n}{20} \quad vv_n := \frac{n}{2}$$

$$P_{cruise_n} := \frac{Power_{cruise}(vv_n\cdot mph, 100)}{k\cdot watt}$$



Compare Corolla (Solid) vs. Volt (Dotted) Performance:

Read Charge Depletion Mode Data

Read Charge Sustaining Mode Data (**Disabled**)

Data Format in File: Time, Vel, Angular Speed, MPH, Accel(g), Torque(rpm), Power (rpm), Force(v), P(v)

Volt := READPRN("Volt_tVelwMAgTPmFP.prn")

Volt := READPRN("VoltSus_tVelwMAgTPmFP.prn")

Volt := READPRN("http://www.leapcad.com/Transportation/Volt_tVelwMAgTPmFP.prn")

$n := 0..300$

$P_{tot}(v) := F_{tot}(v \cdot mph) \cdot v \cdot mph \cdot hp^{-1}$

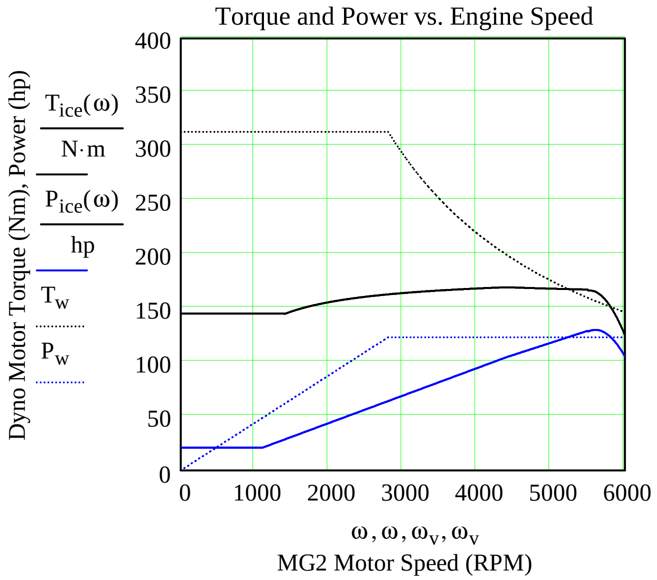
$time_v := Volt^{\langle 0 \rangle}$ $v_v := Volt^{\langle 1 \rangle}$ $\omega_v := Volt^{\langle 2 \rangle} \cdot k$ $mph_v := Volt^{\langle 3 \rangle}$ $g_v := Volt^{\langle 4 \rangle}$ $tz_n := \frac{n}{10}$

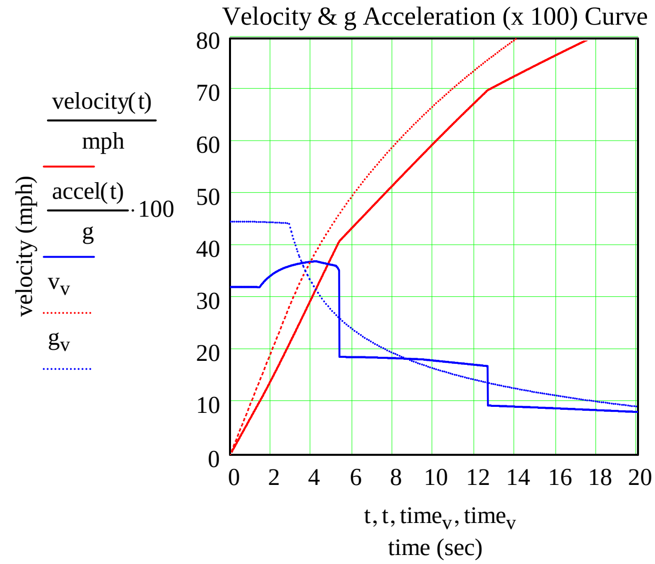
$q := (N \cdot m)^{-1}$ $T_w := Volt^{\langle 5 \rangle}$ $P_w := Volt^{\langle 6 \rangle} \cdot \frac{kW}{hp}$ $F_v := Volt^{\langle 7 \rangle}$ $Pv_v := Volt^{\langle 8 \rangle}$ $P_{cruiseV} := Volt^{\langle 9 \rangle}$

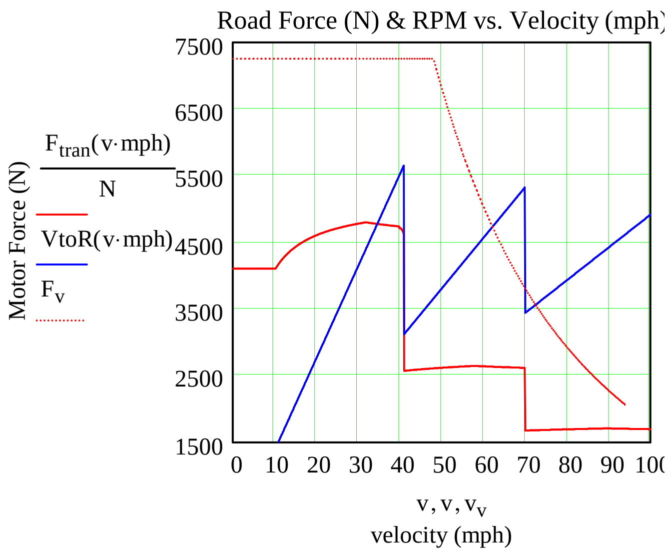
$\omega_{x_n} := \frac{6000 \cdot n}{200}$ $Ttot_n := T_{tot}(\omega_{x_n}) \cdot q$ $Tm2_n := T_{m2}(\omega_{x_n}) \cdot q$ $Tice_n := T_{icem2}(\omega_{x_n}) \cdot q$ $Vx_n := velocity(tz_n)$

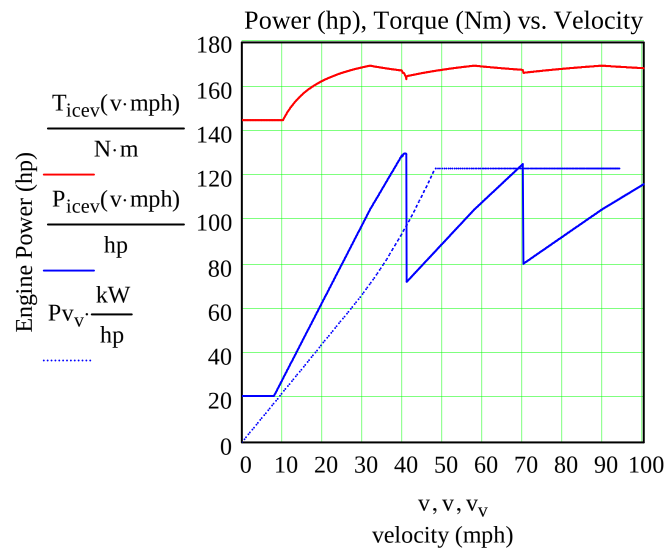
$Ax(Vx) := \frac{(F_{tot}(Vx \cdot mph) - Fo(Vx \cdot mph)) \cdot 100}{k_m \cdot M_{gross} \cdot g}$ $ax_n := Ax(Vx_n)$ $Ft_n := \frac{F_{tot}(Vx_n \cdot mph)}{N}$ $Pt_n := \frac{P_{tot}(Vx_n \cdot mph)}{hp}$

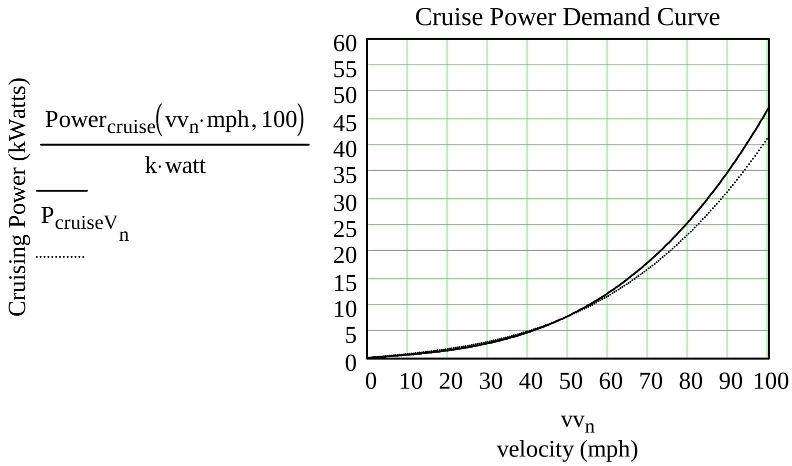
$PreWtTotM2ICVA := augment(\omega_x, tz, Ttot, Tm2, Tice, Vx, ax, Ft, Pt)$ WRITEPRN("CorPB0.txt") := PreWtTotM2ICVA










Cruise Power Demand Curve
Cruising Power (kWatts)
Power_cruise(vv_n·mph, 100) / k·watt
P_cruiseV_n
vv_n
velocity (mph)
0 10 20 30 40 50 60 70 80 90 100
0 5 10 15 20 25 30 35 40 45 50 55 60