Vehicle Dynamics and Simulation

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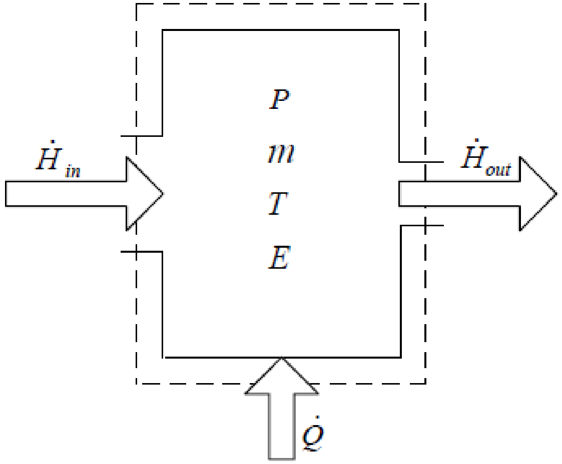
Torque Generation

Intake manifold



- Can be represented as open system of constant volume.
- System stores mass and energy, represented by state variables P and T.
- Mass balance;

$$\frac{dm}{dt} = \dot{m}_{in} - \dot{m}_{out} \qquad (1)$$

- Energy balance;

$$\frac{dE}{dt} = \dot{m}_{in} h_{0_{in}} - \dot{m}_{out} h_{0_{out}} + \dot{Q} \qquad (2)$$

- Where;

$$h_0 = C_p T + \frac{u^2}{2}$$

And the energy within the volume is;

$$E = mc_v T + \frac{mu^2}{2} + mgz$$

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Intake manifold

- Making some assumptions
  - GPE change is 0
  - KE change is 0
- So that;

$$E = mc_vT$$

$$h_0 = c_pT \qquad (3)$$

- Taking the derivative wrt to t;

$$\frac{dE}{dt} = c_vT\frac{dm}{dt} + c_vm\frac{dT}{dt} \qquad (4)$$

- And by substitution (1, 3, 4 into 2);

$$c_vT(\dot{m}_{in} - \dot{m}_{out}) + c_vm\frac{dT}{dt} = \dot{m}_{in}C_pT_{in} - \dot{m}_{out}c_pT_{out} + \dot{Q} \qquad (5)$$

Intake manifold

- Coupling the energy and mass balances using the ideal gas law;

$$m = \frac{PV}{RT} \qquad (6)$$

- Taking the derivative;

$$\frac{dm}{dt} = \frac{V}{RT}\frac{dP}{dt} - \frac{PV}{RT^2}\frac{dT}{dt} \qquad (7)$$

- Substituting (1, 6 and 7 into 5) and assuming $T_{out} = T$;

$$\boxed{\frac{dT}{dt} = \left[c_p\dot{m}_{in}T_{in} - c_p\dot{m}_{out}T - c_vT\dot{m}_{in} + \frac{dQ}{dt}\right]\frac{RT}{c_vPV}} \qquad (8)$$

$$\boxed{\frac{dP}{dt} = \left[c_p\dot{m}_{in}T_{in} - c_p\dot{m}_{out}T + \frac{dQ}{dt}\right]\frac{R}{c_vV}} \qquad (9)$$

And;

$$\frac{dQ}{dt} = hA_{wall}(T_{wall} - T) \qquad (7)$$

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Torque model

- Torque produced is a function of;
  - Spark advance
  - Inducted air mass flow
  - AFR
- Data is usually obtained experimentally and incorporated within a regression model.
- Friction torque is deducted (imep – bmep) to establish output torque.
- Fmep is calculated;

$$fmep = 0.97 + 0.15\left(\frac{N}{1000}\right) + 0.05\left(\frac{N}{1000}\right)^2$$

- And;

$$T_f = \frac{fmepV_{sw}}{4\pi} = \frac{0.97 + 0.15\left(\frac{N}{1000}\right) + 0.05\left(\frac{N}{1000}\right)^2 V_{sw}}{4\pi}$$

Parameterisation effort

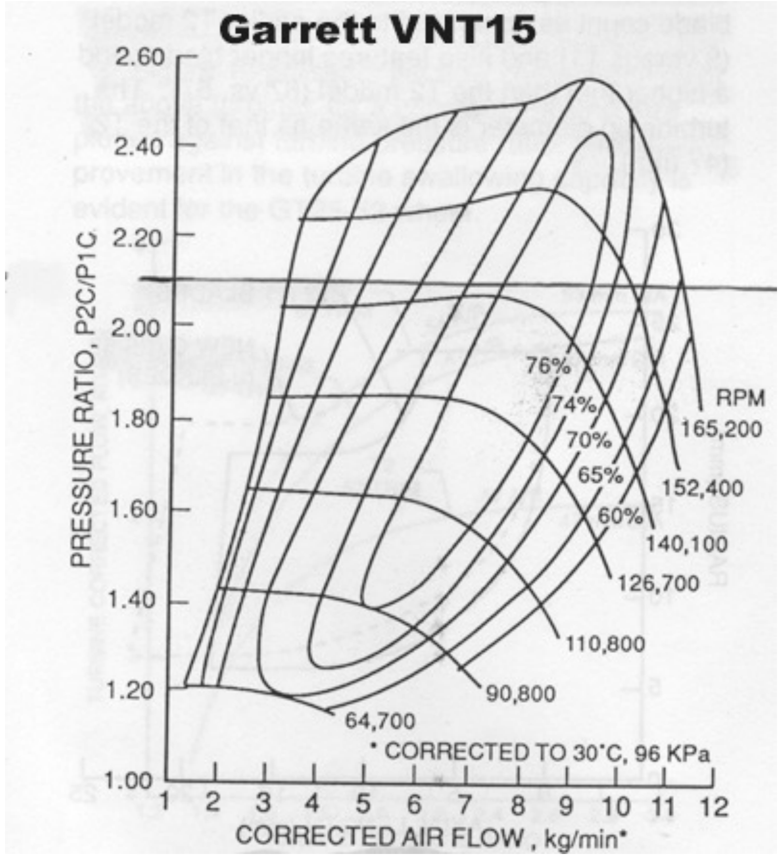
- Model has 5 unknown parameters, C_d, η_{vol}, h, V and V_{disp}.
- With $\eta_{vol} = f(P, T, N, IVO, EVC)$
- η_{vol} is obtained by experiment at some P, T, N, IVO, EVC. Recall;

$$\eta = \frac{120\dot{m}_{actual}}{\rho V_{disp} N_{eng}}$$

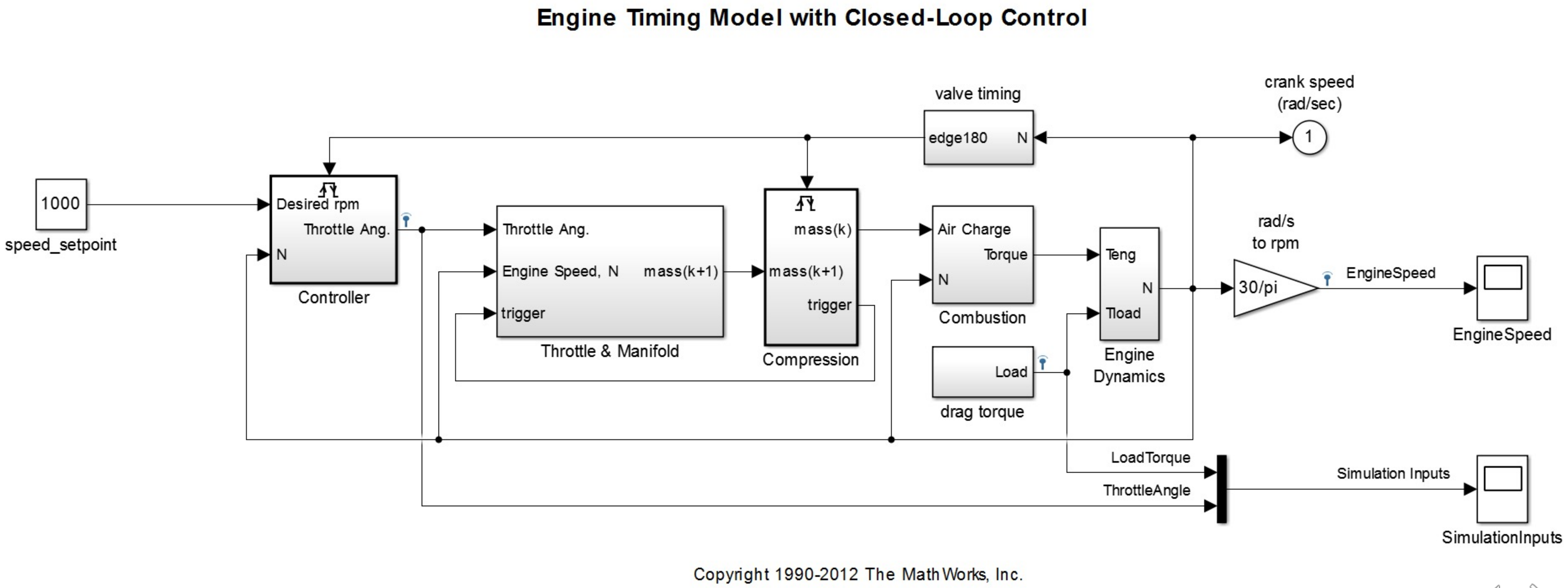
- C_d is also experimentally obtained (usually on flow rigs)
- Obtaining h in reality is very difficult and this is normally one of the tuned parameters.
- V and V_{disp} are obtained relatively easily but can also be used to tune the model response to match reality.

Other considerations

- Adding a turbocharger complicates matters significantly and introduces a causality loop.
  - The loop is normally broken by a delay.
- Heat transfer from the exhaust manifold has a significant effect on the turbo performance.
- Errors in the 'turbo loop' are accumulated within the loop.
- Each additional volume adds two model states (T and P) increasing significantly the computational burden.
- Volumes of very different sizes result in stiff models i.e. slow and fast dynamics.



Crossley and Cook Model



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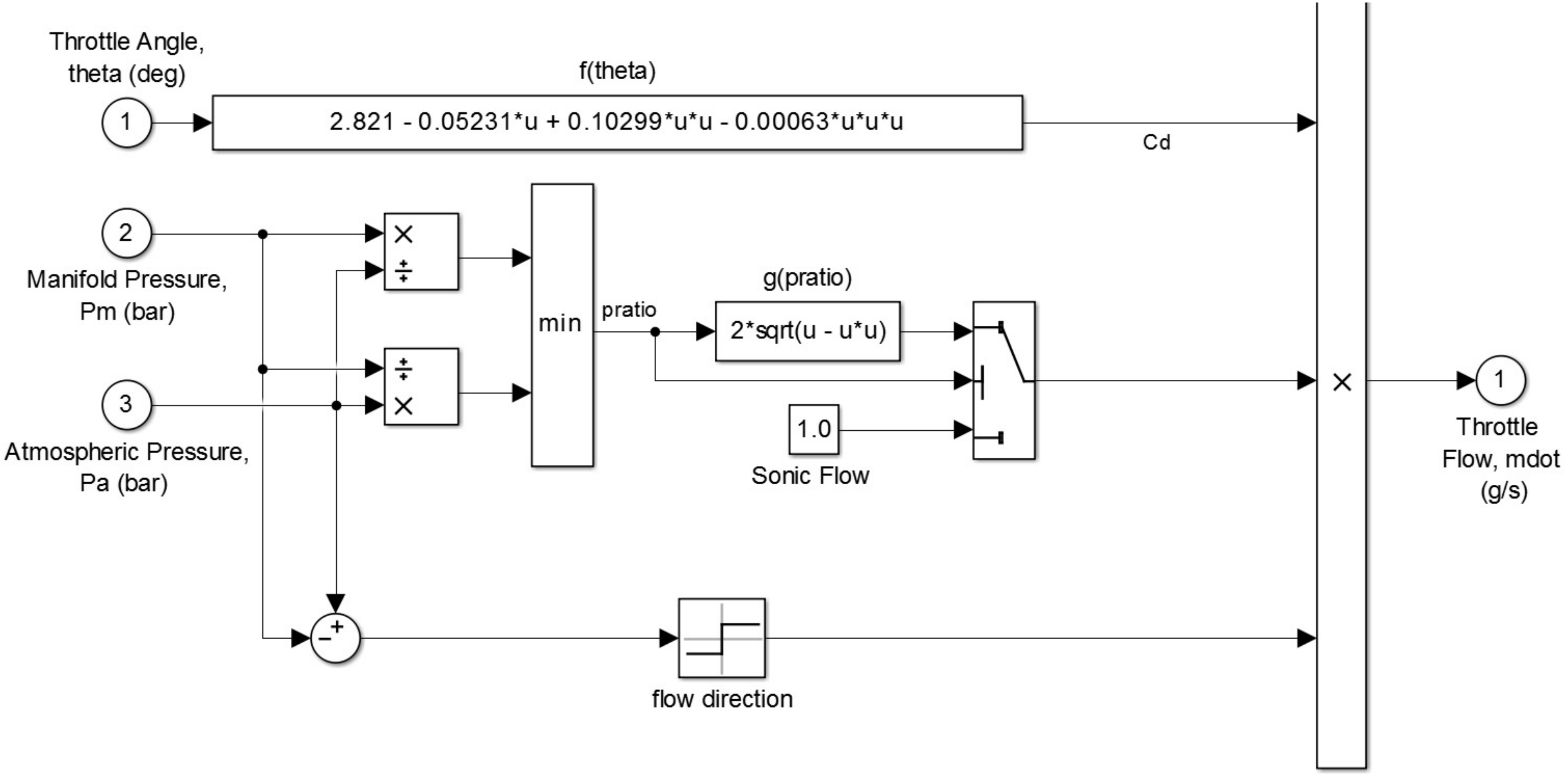
Crossley and Cook Model

Throttle



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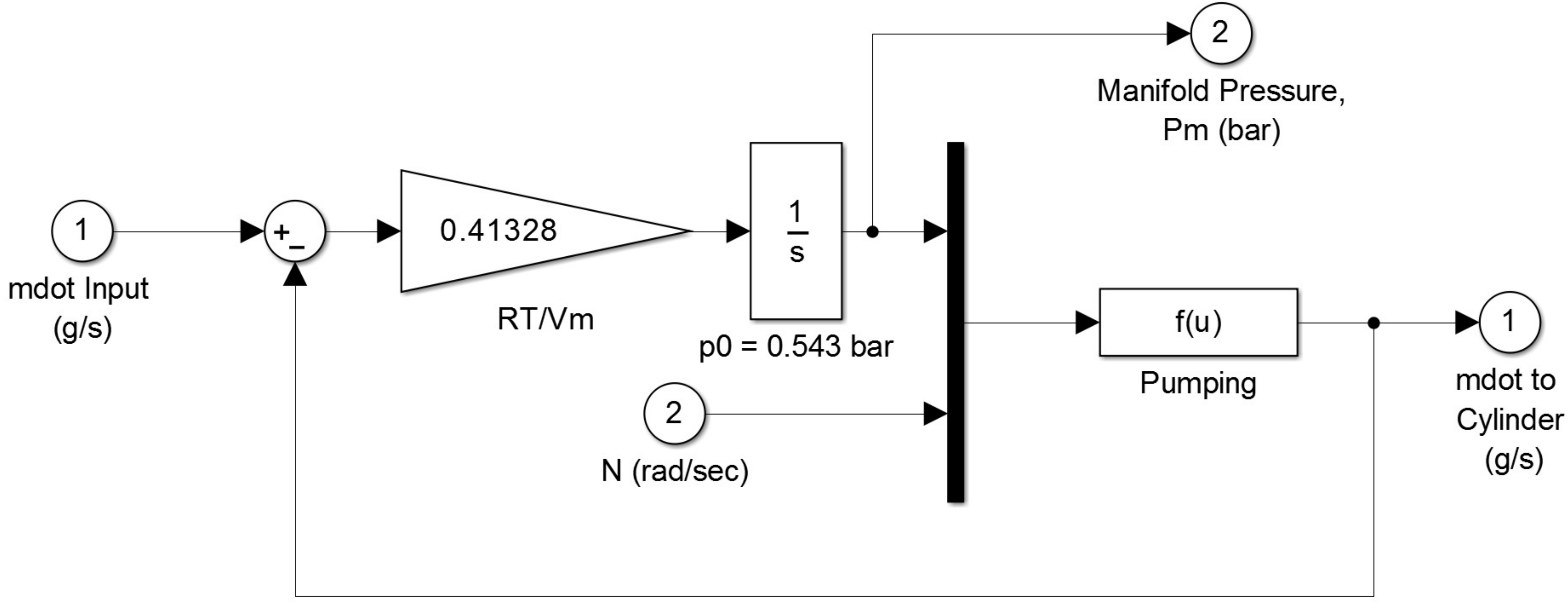
Crossley and Cook Model

Intake Manifold



Crossley and Cook Model

Torque Generation