Supplementary Material

1 NONLINEAR ENGINE MODEL

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\begin{aligned}
\dot{x_1} &= \dot{P}_{bm} = \frac{\gamma_{bm} R_{bm}}{V_{bm}} [W_{comp} T_{cac} - W_{thr} T_{bm} - W_{byp} T_{bm}] \\
\dot{x_2} &= \dot{P}_{im} = \frac{\gamma_{im} R_{im}}{V_{im}} [W_{thr} T_{bm} - W_{cyl} T_{im}] \\
\dot{x_3} &= \dot{P}_{em} = \frac{\gamma_{em} R_{em}}{V_{em}} [W_{cylout} T_{cylout} - W_{turb} T_{em} - W_{wg} T_{em}] \\
\dot{x_4} &= \dot{T}_{bm} = \frac{R_{bm} T_{bm}}{P_{bm} V_{bm}} [W_{comp} (\gamma_{cac} T_{cac} - T_{bm}) \\
&\qquad - (W_{thr} + W_{byp})(\gamma_{bm} T_{bm} - T_{bm})] \\
\dot{x_5} &= \dot{T}_{im} = \frac{R_{im} T_{im}}{P_{im} V_{im}} [W_{thr} (\gamma_{bm} T_{bm} - T_{im}) - W_{cyl} (\gamma_{im} T_{im} - T_{im})] \\
\dot{x_6} &= \dot{T}_{em} = \frac{R_{em} T_{em}}{P_{em} V_{em}} [W_{cylout} (\gamma_{cylout} T_{cylout} - T_{em}) \\
&\qquad - (W_{turb} + W_{wg})(\gamma_{em} T_{em} - T_{em})] \\
\dot{x_7} &= \dot{\omega}_{tc} = \frac{Z_{turb} - Z_{comp}}{I_{tc} \omega_{tc}} \\
\dot{x_8} &= \dot{F}_{ub,bm} = \frac{R_{bm} T_{bm}}{P_{bm} V_{bm}} [W_{inlet} (1 - F_{ub,bm}) + W_{egrl} (F_{ub,em} - F_{ub,bm})] \\
\dot{x_9} &= \dot{F}_{b,bm} = \frac{R_{bm} T_{bm}}{P_{bm} V_{bm}} [W_{inlet} (0 - F_{b,bm}) + W_{egrl} (F_{b,em} - F_{b,bm})] \\
\dot{x_{10}} &= \dot{F}_{ub,im} = \frac{R_{im} T_{im}}{P_{im} V_{im}} [W_{thr} (F_{ub,bm} - F_{ub,im})] \\
\dot{x_{11}} &= \dot{F}_{b,im} = \frac{R_{im} T_{im}}{P_{im} V_{im}} [W_{thr} (F_{b,bm} - F_{b,im})] \\
\dot{x_{12}} &= \dot{F}_{ub,em} = \frac{R_{em} T_{em}}{P_{em} V_{em}} [W_{cylout} (F_{ub,cylout} - F_{ub,em})] \\
\dot{x_{13}} &= \dot{F}_{b,em} = \frac{R_{em} T_{em}}{P_{em} V_{em}} [W_{cylout} (F_{b,cylout} - F_{b,em})]
\end{aligned}
\tag{S1}
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where P, V, T, R, γ, W, Z, I denote the pressure, volume, temperature, mass-specific gas constant, heat capacity ratio, mass flow rate, power, inertia, respectively. Subscripts of bm, im , em , $comp$, thr , byp , $egrl$, cyl , $cylout$, $turb$, wg, tc, cac, denote boost manifold, intake manifold, exhaust manifold, compressor, throttle, bypass, low pressure EGR, cylinder, cylinder out, turbine, waste-gate, turbo-charger, charge air cooler, respectively.

The cylinder charge flow rate W_{cyl} is modeled by the following speed-density equation:

$$W_{cyl} = \frac{\eta_{vol} P_{im} V_d \omega}{120 R T_{im}} \tag{S2}$$

where V_d is the displaced volume for the whole engine and η_{vol} is the volumetric efficiency. η_{vol} is derived based on the energy-balance method proposed in (Kocher et al., 2012)(Van Alstine et al., 2013).

The compressor and turbine sub-models are based on the map reduction method proposed in (Stricker et al., 2014).

2 UNKNOWN DISTURBANCE ESTIMATION

Table S1. Unknown Disturbance Estimation

State	γ_1	γ_2	μ	σ	Skewness Correction	Kurtosis Correction	$B_w(i,i)$
x_1	0.280	-1.27	8.21e4	2.99e5	eq. (S4a)	eq. (S5)	2.73e5
x_2	-0.0745	-1.57	-8.27e4	2.11e5	eq. (S3)	eq. (S5)	3.31e5
x_3	-0.0945	-0.413	-1.29e5	1.99e5	eq. (S3)	/	1.99e5
x_4	-0.309	-1.41	-26.9	276.0	eq. (S4a)	eq. (S5)	350.0
x_5	-0.0777	-1.55	-47.1	121.0	eq. (S3)	eq. (S5)	187.0
x_6	-1.61e-3	-1.65	-818.0	2011.0	eq. (S3)	eq. (S5)	3322.0
x_7	-0.576	-0.75	3.55e5	9.81e5	eq. (S4b)	/	1.34e6
x_8	0.533	-0.832	0.184	0.249	eq. (S4a)	/	0.0651
x_9	-0.533	-0.832	-0.184	0.248	eq. (S4a)	/	0.0636
x_{10}	6.98	76.3	1.05e-4	0.00724	eq. (S4a)	/	7.14e-3
x_{11}	-6.98	76.3	-1.05e-4	0.00724	eq. (S4a)	/	7.14e-3
x_{12}	3.06e-3	-0.625	-1.11e-4	5.56e-4	eq. (S3)	/	5.56e-4
x_{13}	-3.06e-3	-0.625	1.11e-4	5.56e-4	eq. (S3)	/	5.56e-4
x_{14} - x_{20}	/	/	/	/	/	/	0

$$B_w(i,i) = \sigma(i) \tag{S3}$$

$$B_w(i,i) = \sigma_i - |\mu_i| \quad if \quad \gamma_{1,i}\mu_i > 0 \tag{S4a}$$

$$B_w(i,i) = \sigma_i + |\mu_i| \quad if \quad \gamma_{1,i}\mu_i < 0 \tag{S4b}$$

$$B_w(i,i) = B_{w0}(i,i)\,|\gamma_{2,i}| \tag{S5}$$

REFERENCES

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