

# Plant Modeling I/F Guidelines for Vehicle Development (ver.4.1)

September, 2021

## **Objective of this guideline**

This guideline has the purpose of the expansion of the model distribution, the quality improvement of model based reconciliation and human resources who can accomplish model based development in the automotive industry, by integrating the I/Fs as domestic de facto standard, for model based use in each layer of automotive manufacturers, suppliers and auto industry clusters.

Furthermore, this guideline is expected to further promote this purpose by providing the vehicle model that conform this guideline.

## **Key points of this guideline**

This guideline:

- is applied to systems which own energy.
- defines the direction of energy flow.
- defines physical signals between subsystems and their directions and unit.
- provides the vehicle model that conforms to this guideline.

## Contents

Terminology .....	1
Chapter 1 : Guideline Principle.....	2
1 . Assumption in the guideline .....	2
(1) Assumption .....	2
(2) Specified Items .....	2
2 . Basic Principle .....	3
(1) First Principle (Variables between Each Plant Models).....	4
(2) Second Principle (Energy Flow Direction).....	5
(3) Third Principle (Input/output Direction of Variable).....	6
(4) Forth Principle (Positive/Negative of Input/Output) .....	7
(5) Fifth Principle (Unit and Quantifier).....	8
Chapter 2 : Examples of the Guideline .....	9
1 . Examples of the vehicle systems for each performance .....	9
(1) Example for fuel economy .....	9
(2) Example for vehicle dynamic performance .....	15
(3) Example for NVH(Noise, Vibration, Harshness).....	20
(4) Example for EV (Electric Vehicle) .....	21
Chapter 3 : Subsystem I/F (interface) Definition Document in an Example of Automobile .....	22
1 . Utilization of Subsystem I/F Definition Document .....	22
2 . Format of Subsystem I/F Definition Document .....	22
3 . Example of subsystem definition document (fuel consumption) .....	23
(1) Engine model (power source model of mechanical system).....	23
(2) Flywheel model.....	24
(3) Transmission model.....	25
(4) Differential gear model.....	26
(5) Drive shaft model.....	27
(6) Brake system model .....	28
(7) Tire model .....	29
(8) Suspension model .....	30

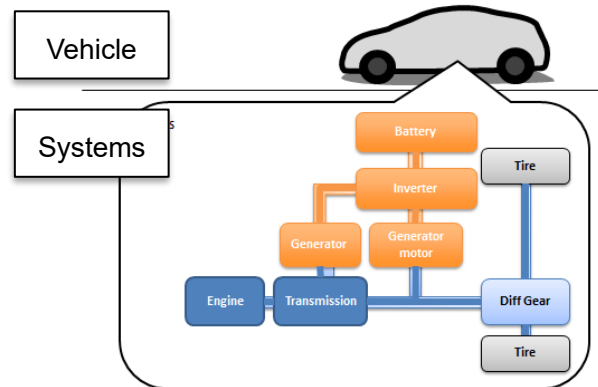
(9) Body rigid-body motion/drive system model .....	31
(10) Body (air resistance) model .....	32
(11) Alternator model .....	33
(12) Low voltage charging system model .....	34
(13) Starter model .....	35
(14) Model of each electric system.....	36
(15) Battery temperature control system model .....	37
(16) Voltage conversion system model.....	38
(17) High voltage charging system model .....	39
(18) Voltage conversion system (pressurization) model .....	40
(19) Motor drive system model.....	41
(20) Air-conditioning system Model .....	42
(21) P/T thermal System Model.....	43
(22) Power Electronics Cooling System Model .....	44
(23) Heat Sink Model.....	45
(24) Engine Model (P/T thermal) .....	46
(25) Transmission Model (P/T thermal) .....	47
(26) Differential gear Model (P/T thermal) .....	48
(27) High temperature cooling system Model (P/T thermal) .....	49
(28) HVAC Model (P/T thermal).....	50
4. Example of subsystem definition document (vehicle dynamic performance) .....	51
(1) Steering system Model (dynamic performance).....	51
(2) Drive torque Model (dynamic performance).....	52
(3) Tire Model (dynamic performance) .....	53
(4) Brake system Model (dynamic performance).....	54
(5) Suspension/ Unsprung Model (dynamic performance) .....	55
(6) Vehicle Model (dynamic performance).....	56
(7) Road surface Model (dynamic performance) .....	57
5. Example of subsystem definition document (NVH) .....	58
(1) Tire Model (NVH) .....	58
(2) Unsprung Model (NVH).....	59
(3) Suspension system Model (NVH) .....	60

(4) Vehicle (Sprung mass) Model (NVH) .....	61
(5) Engine mount Model (NVH) .....	62
(6) Engine inertia Model (NVH) .....	63
(7) Seat Model (NVH).....	64
(8) Driver Model (NVH).....	65
(9) Road surface Model (NVH).....	66
<Reference document> .....	67

## Terminology

### ① Systems

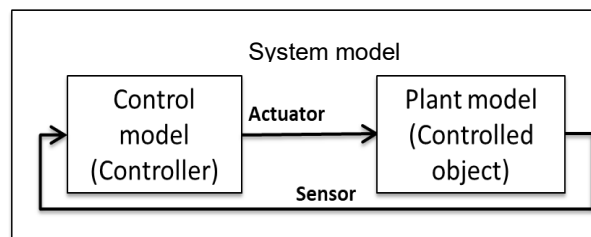
Systems is defined as top-layer parts that compose the vehicle.



**Fig. 1 Definition of system**

### ② Control model/Plant model

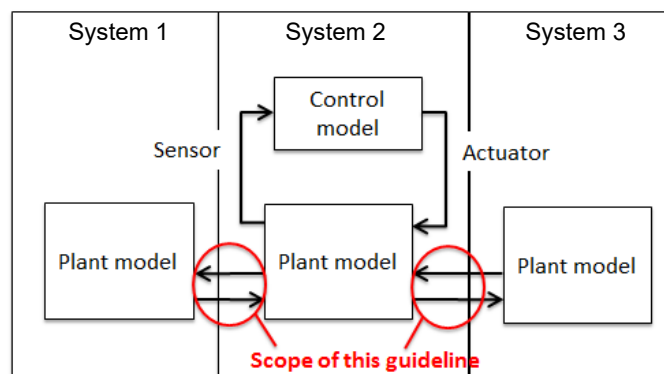
Systems are categorized into 2 types: control models which control devices, and plant models which are controlled by control models.



**Fig. 2 Positioning of plant model/control model**

### ③ Scope of plant model I/F (interface) guideline

This guideline is applied to I/F between plant models in system.



**Fig. 3 Scope of plant model I/F (interface) guideline**

## Chapter 1 : Guideline Principle

### 1 . Assumption in the guideline

#### (1) Assumption

The connections between each plant model in systems need to be considered various physics including kinematics, electricity, heat, etc. To this end, I/F between systems of plant models shall be easy to design by energy flow.

Besides, the following points shall be also considered:

- It should be easy to model.
- It should not require heavy calculation.
- Modeling should be feasible.

#### (2) Specified Items

This guideline specifies the following items in plant models:

- ①Types of input/output variables
- ②Energy flow between systems
- ③Direction of input/output
- ④Positive/negative of through variables
- ⑤Unit/quantifier

## 2. Basic Principle

The basic principles for connection between plant models are specified as follows:

**Table. 1 Basic principle of plant model I/F guideline**

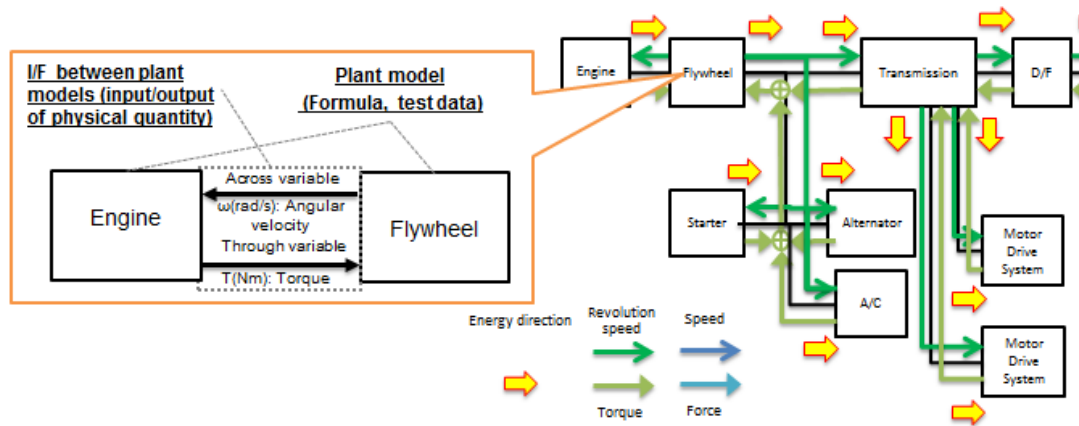
Basic principle	
1 <sup>st</sup>	Plant models shall be connected using across variable and through variable. Across variable and through variable shall be in the opposite direction.
2 <sup>nd</sup>	The flow direction from energy source to energy sink shall be considered positive direction of energy flow.
3 <sup>rd</sup>	Based on elements which store the quantity of through variable and across variable, overall I/F shall be defined.
4 <sup>th</sup>	Through variable shall be regarded as positive when its input/output is in the same direction as positive flow of energy. (Regarded as negative when in the different direction)
5 <sup>th</sup>	For input/output, SI units system and SI derived unit system shall be used. For quantifier, JIS standard shall be applied.

In case of deviation from the above, it shall be stated including reasons (using System I/F Definition Document).



## (1) First Principle (Variables between Each Plant Models)

As shown in Fig. 4, plant models shall be connected with across variables and through variables. The direction of through variable's signal and across variable's signal shall be opposite each other.



**Fig. 4 Input/output direction in plant model**

Across variables shall be physical quantity which indicates energy potential while through variables shall be physical quantity which indicates energy flow. The following equation shall hold:

$$\text{Power (W)} = \text{Across variable} \times \text{Through variable}$$

Across variables and through variables in each physical domain are shown in Table. 2.

**Table. 2 Across variable and through variable in each physical domain**

Physical Domain	Across variable	Through variable
Electrical	Potential/voltage	Current
Translational	Velocity	Force
Rotational	Angular velocity	Torque
Heat	Temperature	Heat flow
Incompressible fluid *1	Pressure	Volume flow
Thermal fluid	Temperature	Enthalpy flow
	Pressure	Mass flow Specific enthalpy *2

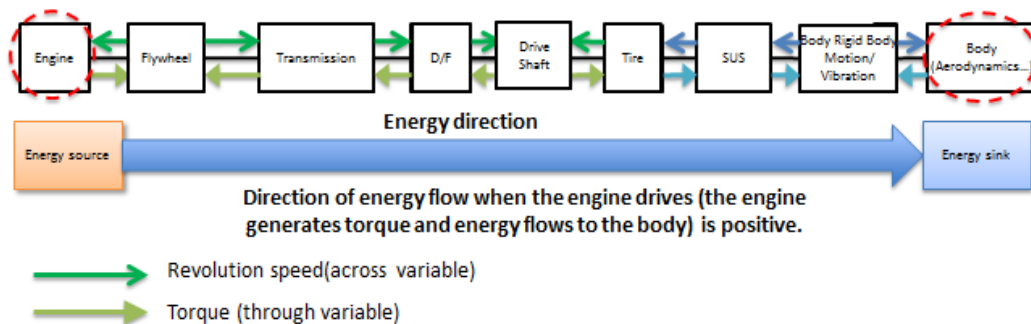
Physical domains which are not shown in Table. 2 shall be discussed and determined in the future.

- \*1 This is an incompressible fluid that does not consider Thermal.
- \*2 The specific enthalpy is not a through variable, but depending on some tools, the divisor may be zero may occur in the calculation if only the enthalpy flow rate is used. Describe as an interface to support various tools. By the way, it can be calculated by the following formula:  

$$\text{the ratio enthalpy (J/kg)} = \text{enthalpy flow rate (J/s)} / \text{mass flow rate (kg/s)}.$$
Please note that if the mass flow rate is 0, specific enthalpy will have a divisor of zero.

## (2) Second Principle (Energy Flow Direction)

The flow direction from energy source to energy sink is defined as positive.  
An example of mechanical system of automobile is shown below:



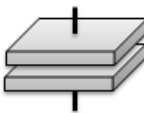



**Fig. 5 Energy flow direction**

Energy source and sink shall be defined considering a whole system. In the plant model of powertrain system used to study fuel consumption or engine performance, the engine is the energy source and the body is the energy sink.



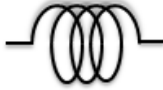
### (3) Third Principle (Input/output Direction of Variable)

The models shown in Fig. 6 receive through variables from adjacent models during sending across variables to them.

	Motion		Electricity	Heat
	Inertia mass	Inertia moment	Condenser	Heat capacity
Model to store energy (receive through variable)				

**Fig. 6 Example of model which stores energy (Across variable output)**

The models shown in Fig. 7 receive across variables from adjacent models during sending through variables to them.

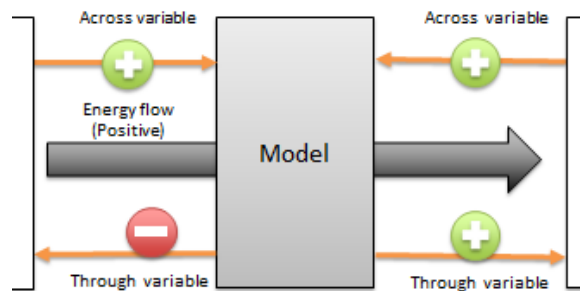
	Motion		Electricity	Heat
	Spring	Torsion spring	Coil	–
Model to store energy (receive across variable)				–

**Fig. 7 Example of model which stores energy (Through variable output)**

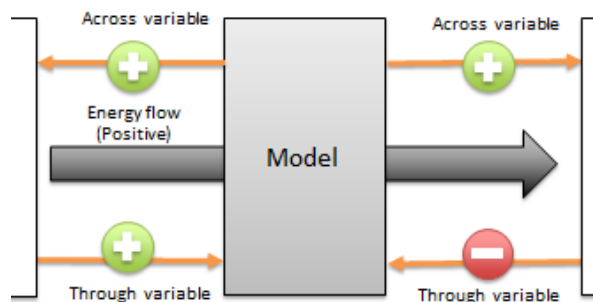
Input/output for other models are determined depend on signal flow of through variables and across variables.

#### (4) Forth Principle (Positive/Negative of Input/Output)

Through variables is defined as positive when it flows in the direction of positive energy flow and regarded as negative when it flows in the opposite direction of energy flow. (Fig. 8 and Fig. 9)



**Fig. 8** Sign of signal when through variable is input



**Fig. 9** Sign of signal when through variable is output

(5) Fifth Principle (Unit and Quantifier)

Units and quantifiers for each physical domain are shown in Table 3.

**Table 3 Units for across variable and through variable**

Domain	Across variable		Through variable			
		Quantifier	Unit		Quantifier	Unit
Electrical	Voltage	V	V	Current	I	A
Translational	Velocity	V	m/s	Force	F	N
Rotational	Angular velocity	$\omega$	rad/s	Torque	M,T	Nm
Heat	Temperature	T	K	Heat flow	$\phi$	W
Incompressible fluid	Pressure	P	N/m <sup>2</sup>	Volume flow	qv	m <sup>3</sup> /s
Thermal fluid	Temperature	T	K	Enthalpy flow	dH	W
	Pressure	P	N/m <sup>2</sup>	Mass flow	qm	kg/s
				Specific enthalpy	h	J/kg

Physical domains which are not shown in Table 3 shall be discussed and determined in the future.

## Chapter 2 : Examples of the Guideline

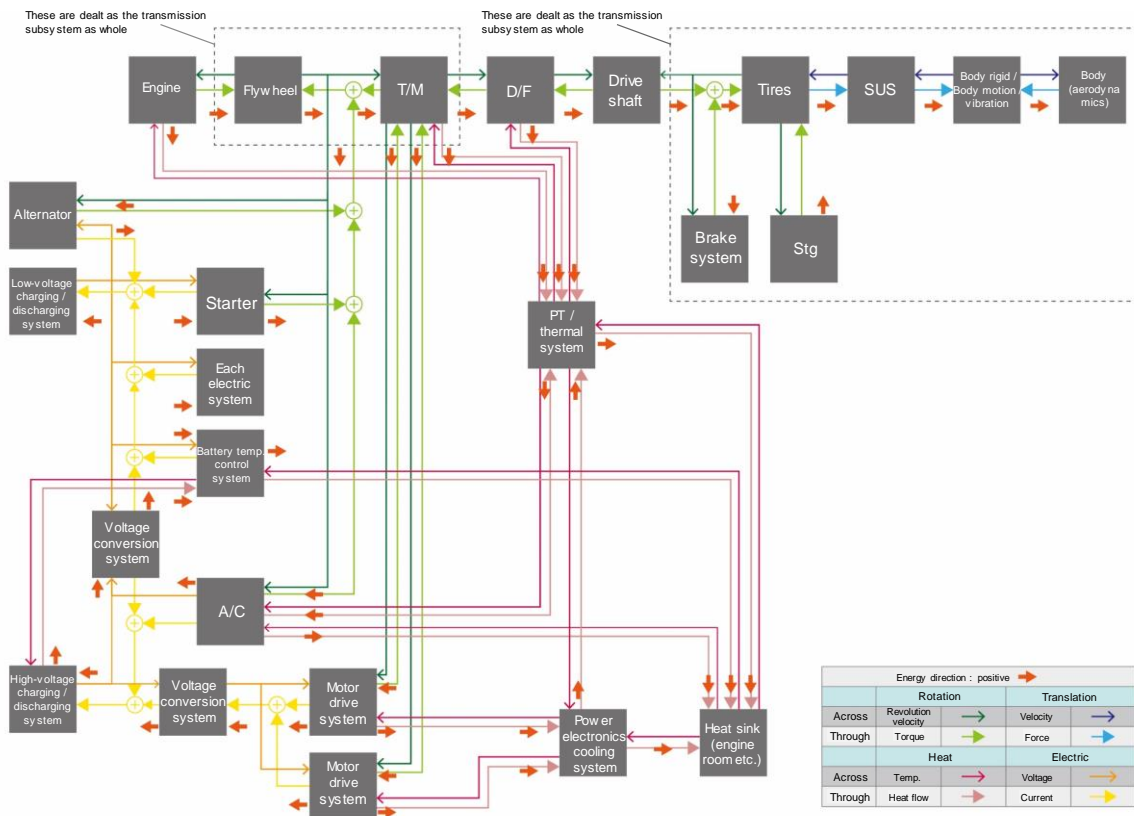
### 1 . Examples of the vehicle systems for each performance

This guideline has the purpose of the expansion of the model distribution, the quality improvement of model based reconciliation and human resources development, by integrating the I/Fs as domestic de facto standard, for model based use in each layer of automotive manufacturers, suppliers and auto industry clusters.

This chapter introduces variables examples.

#### (1) Example for fuel economy

Fig. 10 shows the result that apply the guideline which estimated fuel economy as example object: Series/Parallel Hybrid vehicle.



**Fig. 10 Whole guideline for series parallel hybrid vehicle**

## ① Driving system

Since tires are rotated by energy engine generated, defining the engine as the energy source and the Body as the energy sink, energy flow is determined. (Refer to orange arrows in Fig. 11)

In a flywheel, in accordance with the third principle, through variables are sent from adjacent systems (engine and transmission), and across variables are sent to them. In a drive shaft as well, in accordance with the third principle, across variables are sent from adjacent systems (engine and transmission), and through variables are sent to them. For other systems, the direction of through/across variables is determined based on the flow of these systems. In accordance with the first principle, across variables are connected in the opposite direction to through variables. Fig. 11 illustrates above description.

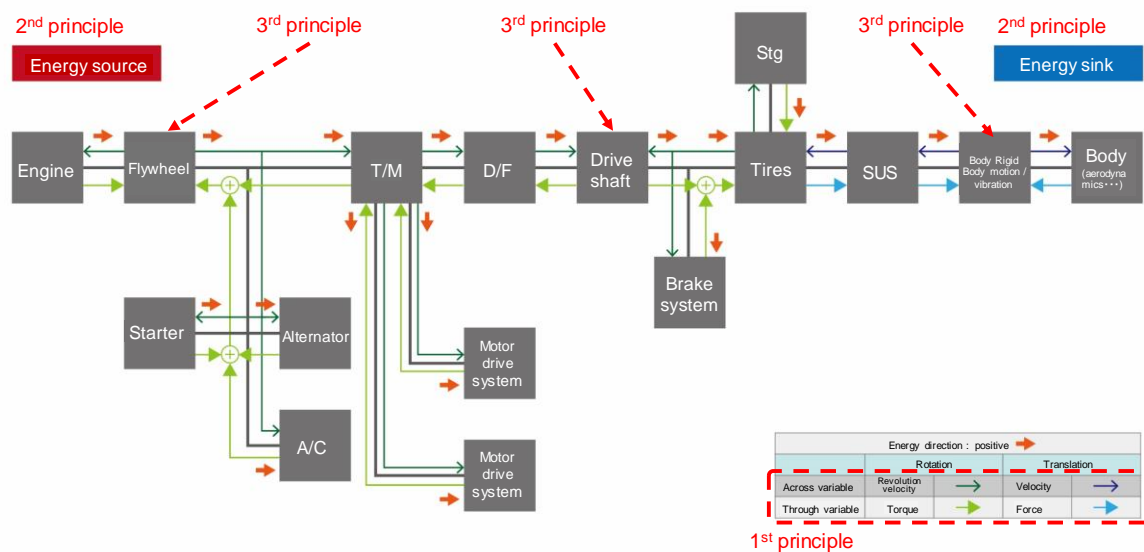


Fig. 11 Example of input/output in a driving system

i. Flywheel

Depending on the types of transmission (MT, AT, CVT, HEV, etc.), the system that handle flywheel varies. (In case of MT, it should be handled the engine. In other cases, it is likely to be handled the transmission. )

In this guideline, I/F is determined regarding the flywheel as a single model.

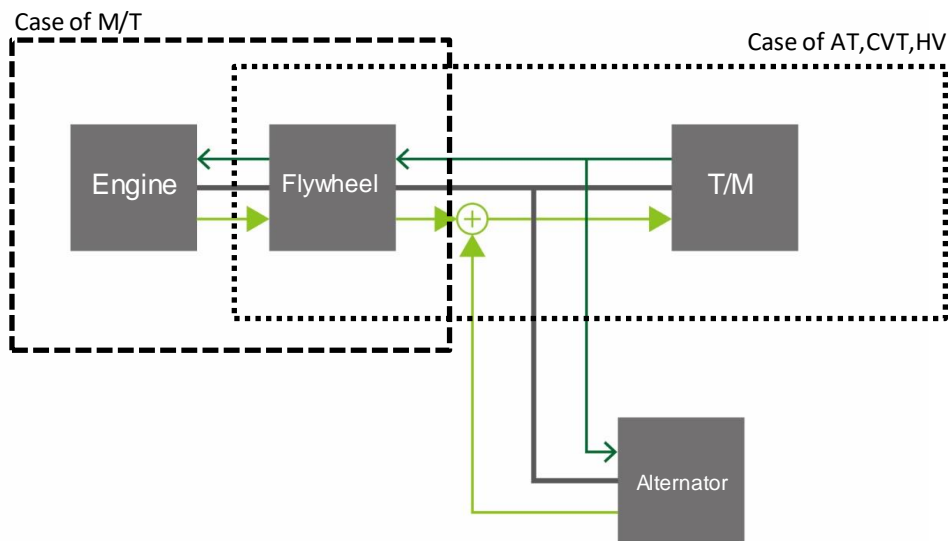


Fig. 12 Example of flywheel



## ② Electric system

For electric systems, I/F is determined by defining systems which generate electric energy (such as generator) as the energy source and parts which consume electric energy as the energy sink respectively. In this case, two MGs, which are motor drive systems, are the energy source. Starter and each electric system are the energy sink because they consume electricity. The alternator is defined as the energy source as it generates electric energy like MGs. Fig. 13 illustrates above description.

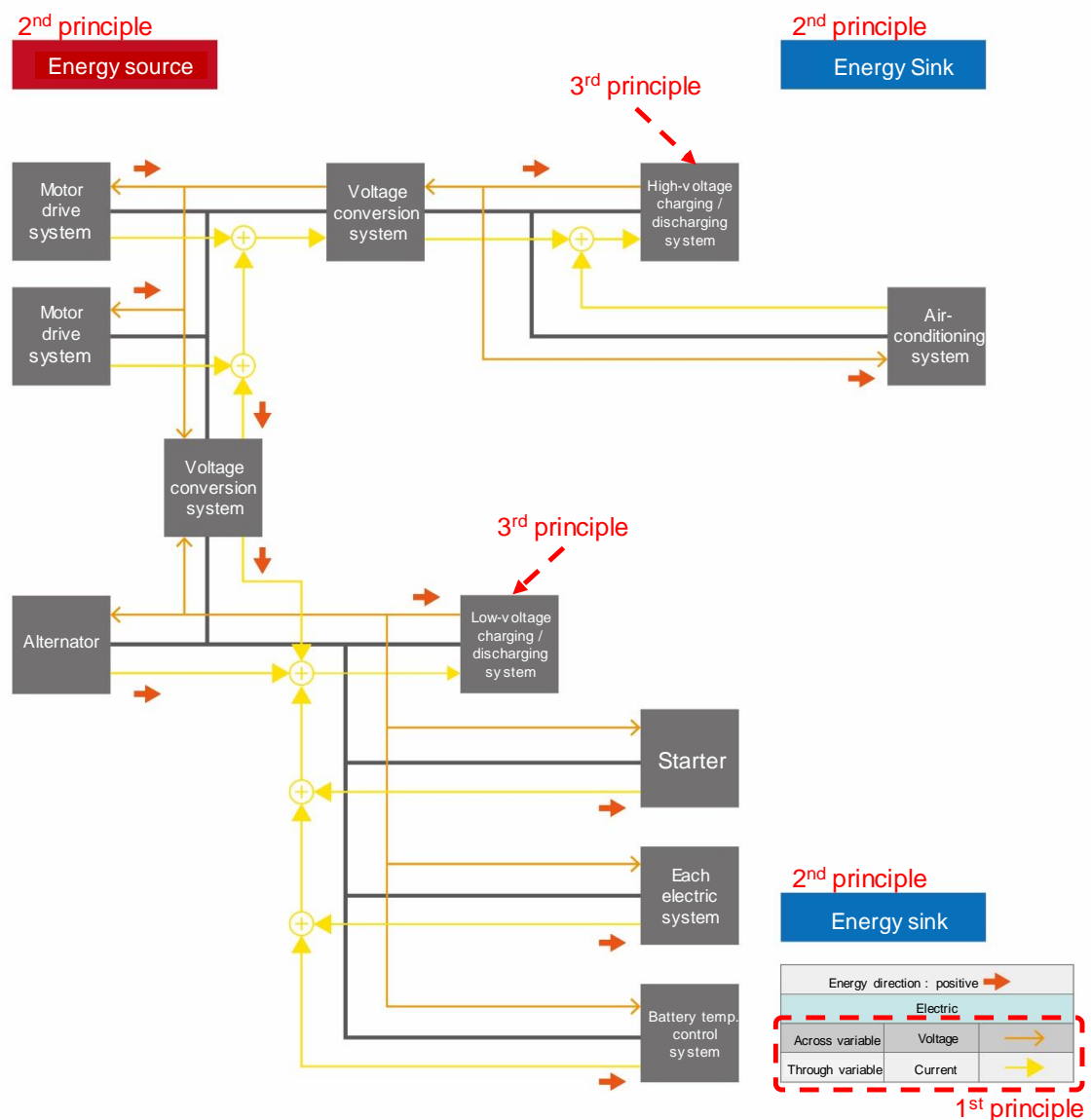


Fig. 13 Example of input/output in electric system

### ③Heat system

For heat systems, individual driving systems and electric systems are the heat sources. Thus these systems are defined as the energy sources, and heat sinks such as engine compartment are defined as the energy sink. In the actual physical phenomenon, heat is transferred from the energy source through P/T thermal system to the energy sink. Fig. 14 illustrates above description.

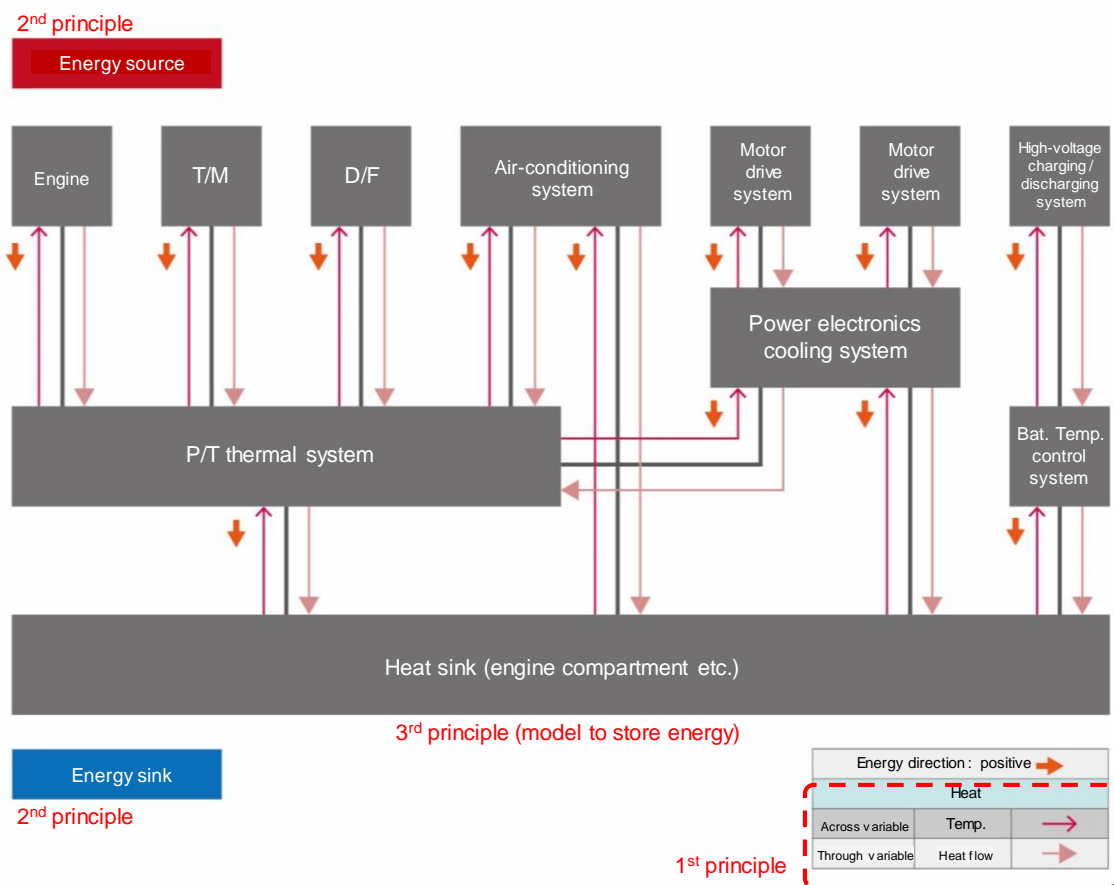
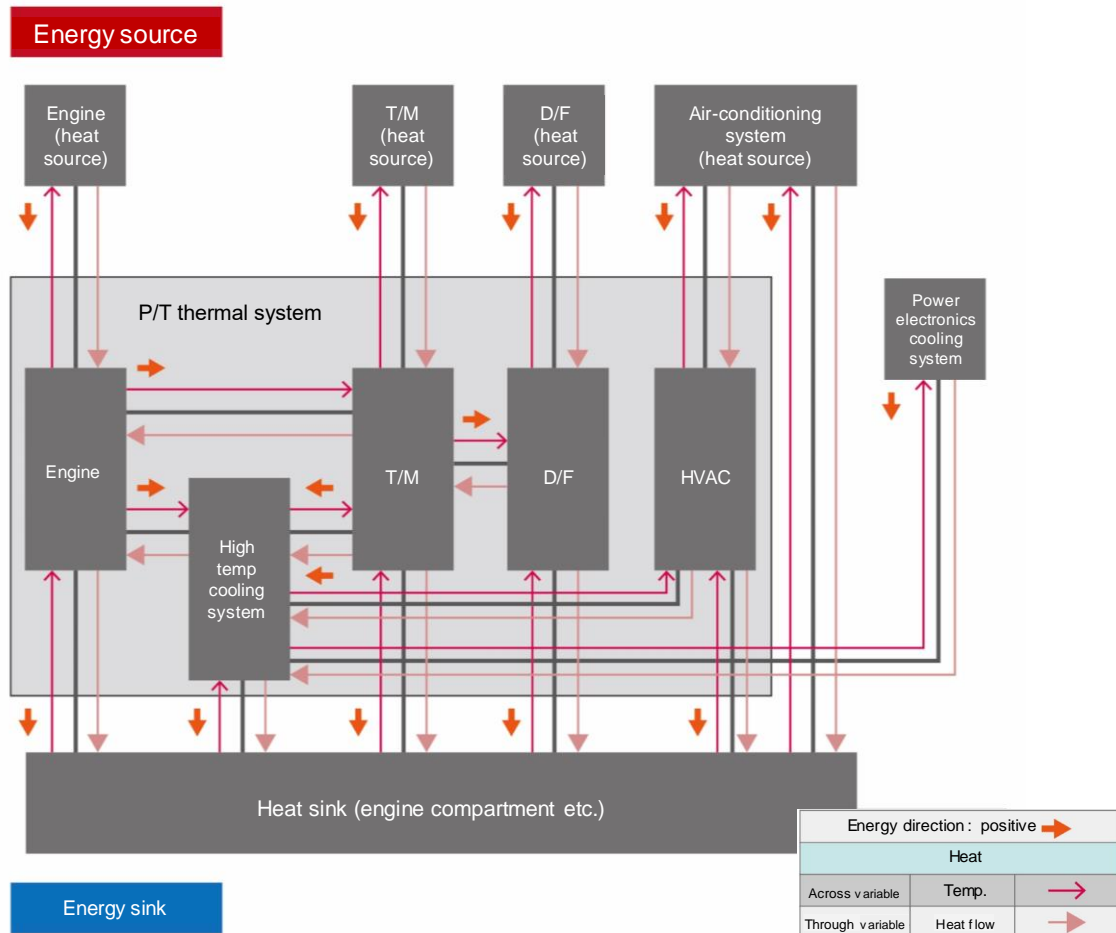


Fig. 14 Example of input/output in a heat system

As an example for P/T thermal system (Fig. 14), an example for engine, transmission and cooling system is shown in Fig. 15.

Please note that thermal resistance between systems is included in both systems in thermal model distribution. So thermal resistance need to be determined which system side have this role.

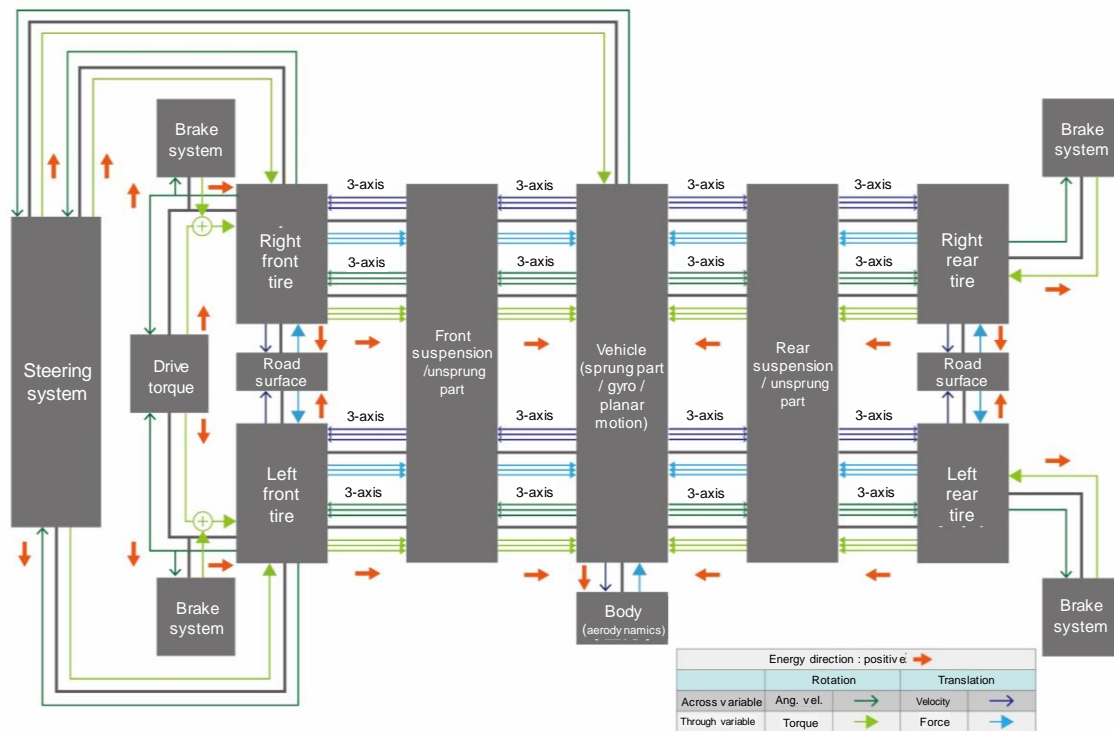


**Fig. 15 Example of input/output in P/T thermal system**

## (2) Example for vehicle dynamic performance

For vehicle dynamic performance, it is necessary to consider the vehicle's center of gravity, steering, tire characteristics and so on, and a steady circular cornering test<sup>1</sup> may be conducted as an evaluation of steering stability performance.

In this guideline, the result applied the guideline is shown in Fig. 16 by using the steady circular turning test as an example.



**Fig. 16 Input/output example of vehicle dynamic performance**

<sup>1</sup> Steady circular cornering is referred to JIS D 1070 or ISO 4138.

In addition, in the case of model distribution based on dynamic performance, inconsistencies are likely to occur in which direction is positive for the across amount (velocity and rotation speed). An example of an international standard coordinate system in the modeling process is shown below.

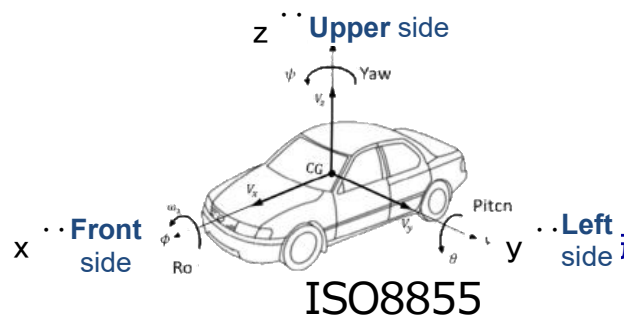


## ① Model making

an example of JIS D 1070 steady circular turning is shown below. (Equivalent to the contents of ISO4138)

### A) Vehicle fixed coordinate system

In the motion of steady circular turning, it is expressed by “intermediate axis system (from JIS D 1070)” and is specified by ISO 8855. As a coordinate system in the translation direction, the positive direction of each axis is X: forward, Y: left, Z: upward. The positive direction of rotation is X: right-handed screw direction  $\phi$  Ro, Y: right-handed screw direction  $\theta$ , Z: right-handed screw direction  $\psi$  Yaw.



**Fig. 17 Coordinate system in ISO8855**

### B) Origin of vehicle fixed coordinates

The origin of the vehicle is not clearly specified because it depends on the test content.

However, since the origin is also specified in the steady circular turning test method JIS D 1070, the content will be introduced in this chapter as a reference for the model that complies with this guidelines.

“The origin is the center of the axial distance in the vertical center plane of the automobile, and the height is fixed to the height of gravity center in the empty car weight state and does not change depending on the loading conditions. “

And the model that complies with this guideline conforms to this content. (Refer to JIS D 0102 or ISO612)

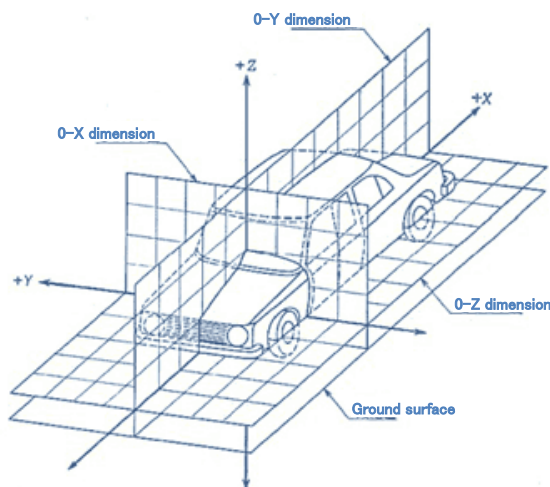
### C) Absolute position coordinate system and origin

It is necessary to set the coordinates for the moving position of the automobile in the absolute position. The ISO8855 coordinate system is adopted as the regulation for the orientation of the coordinate system, and the origin is set optionally.

## ② Parameter setting

A) The vehicle standard system during parameter calculation from the vehicle design drawing

After creating the model, when calculating the dimensional parameters of the vehicle in kinetic performance, the design drawing of the vehicle may be used. The coordinate system that defines the dimensions of the vehicle is defined by the JIS D 0030 three-dimensional coordinate system for automobiles (see ISO 4131). The positive direction is different from the ISO 8855 coordinate system during the above motion.

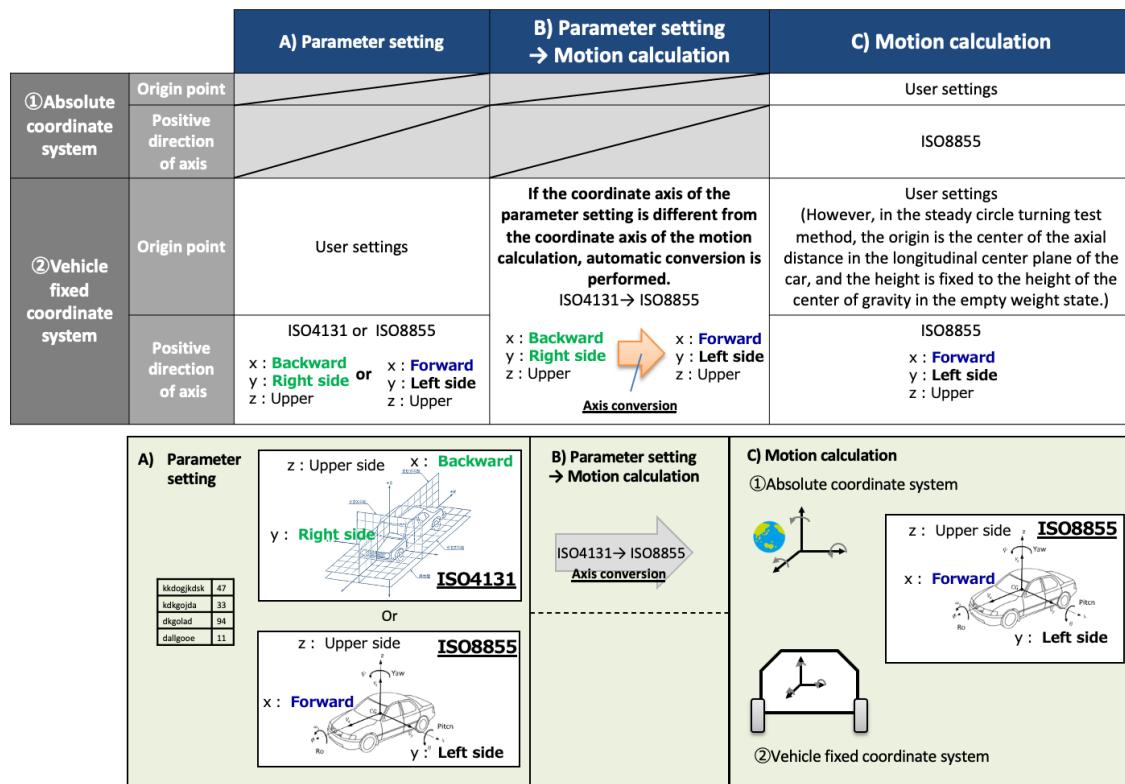


**Fig. 18 Coordinate system during dimensions setting in ISO4131**

In this guidelines, model making and parameter calculation from dimensions have the each provisions. Considering future model distribution, The process in which each joins well is described below.

### ③ Process from parameter setting coordinate system to motion model coordinate system

From ① and ② above, the coordinate system at the time of parameter setting and the coordinate system at the time of motion calculation in the model may be different. This guideline proposes a process of correcting the coordinate axes by performing axis transformation when the coordinate axes in each coordinate system are different.



**Fig. 19 Parameter setting process for model**

Axis transformation in the vehicle fixed coordinate system can be realized by translation of the origin and rotation transformation of the coordinate system.

#### ④ Clarification of vehicle coordinate system in subsystem definition

When the directionality of the axis of the coordinate system such as motion performance is required, the coordinate system that the model assumes can be understood, and The parameters can be set easily by entering a comment in the remarks column of the subsystem definition document to specify the vehicle fixed coordinate system of the assumed vehicle model.

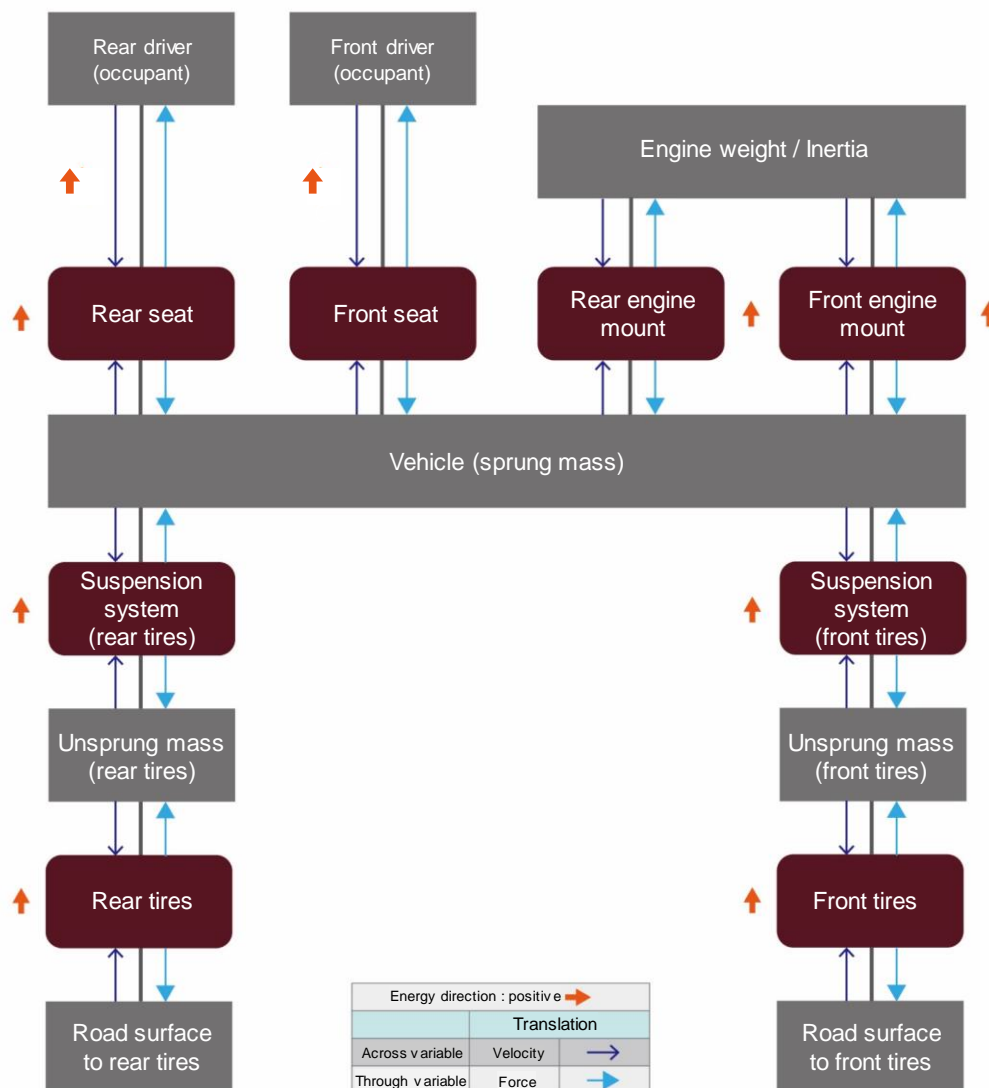


### (3) Example for NVH(Noise, Vibration, Harshness)

For vehicle vibration problem (NVH), it is necessary to consider performances of a power train vibration system (such as a muffled sound) and a vehicle vibration system.

In this guideline, the result is applied the guideline is shown in Fig. 20 by using a low-frequency range (30Hz or less) NVH in a vehicle vibration system considered the ride comfort at a constant speed as an example.

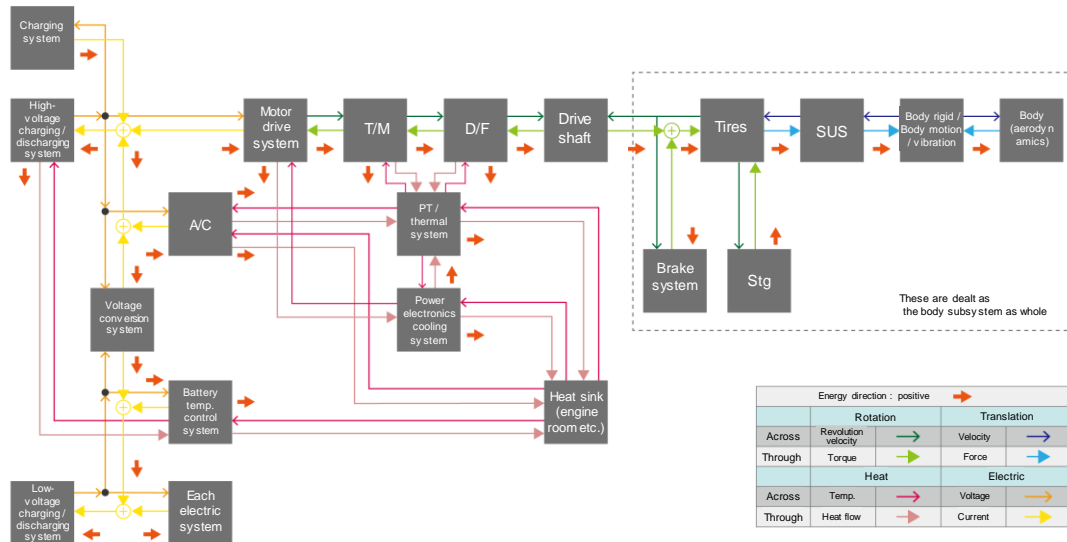
The guideline in Fig. 20 is based on the assumption that all front, rear, left and right tires are tested for ride comfort with inputs from the same road surface in steady driving.



**Fig. 20 Example of NVH guideline for ride comfort in vehicle vibration system**

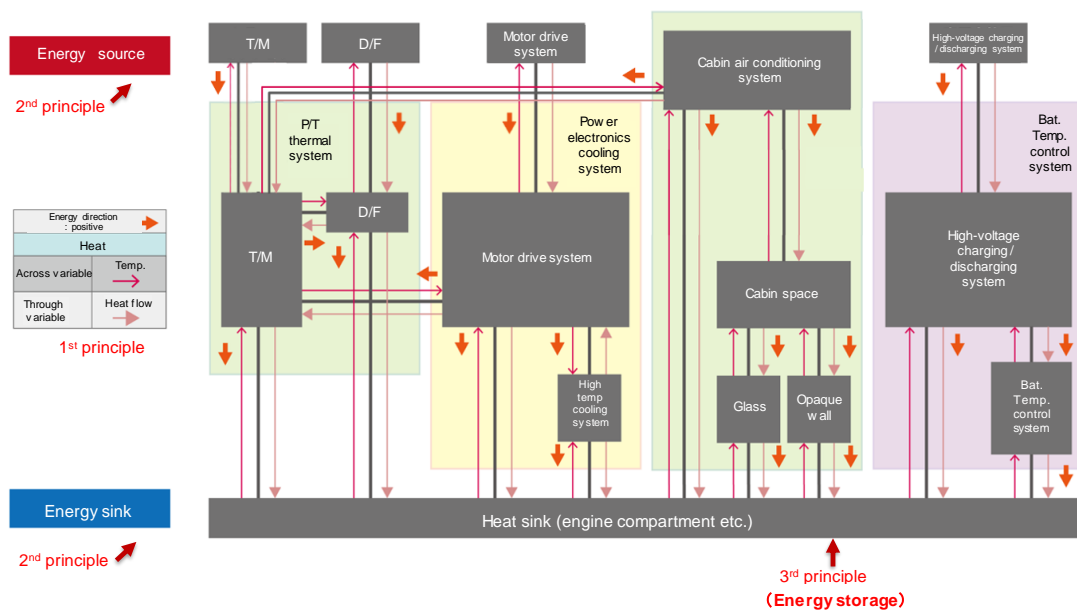
#### (4) Example for EV (Electric Vehicle)

The guidelines are shown in Fig. 21 as examples of studying the cruising distance during cooling and heating of electric vehicles and the temperature control during charging from an external charger.



**Fig. 21 Example of guideline of cruising distance study for EV**

And, Fig. 22 shows the thermal part extracted from the above Fig. 21 case.



**Fig. 22 Example of guideline in each thermal system**

## Chapter 3 : Subsystem I/F (interface) Definition Document in an Example of Automobile

### 1. Utilization of Subsystem I/F Definition Document

When models are distributed, I/F shall be confirmed in accordance with the Subsystem I/F Definition Document.

This definition document may be used to describe I/F such as control models and monitors.

### 2. Format of Subsystem I/F Definition Document

Fig. 23 shows the contents of Subsystem I/F Definition Document.

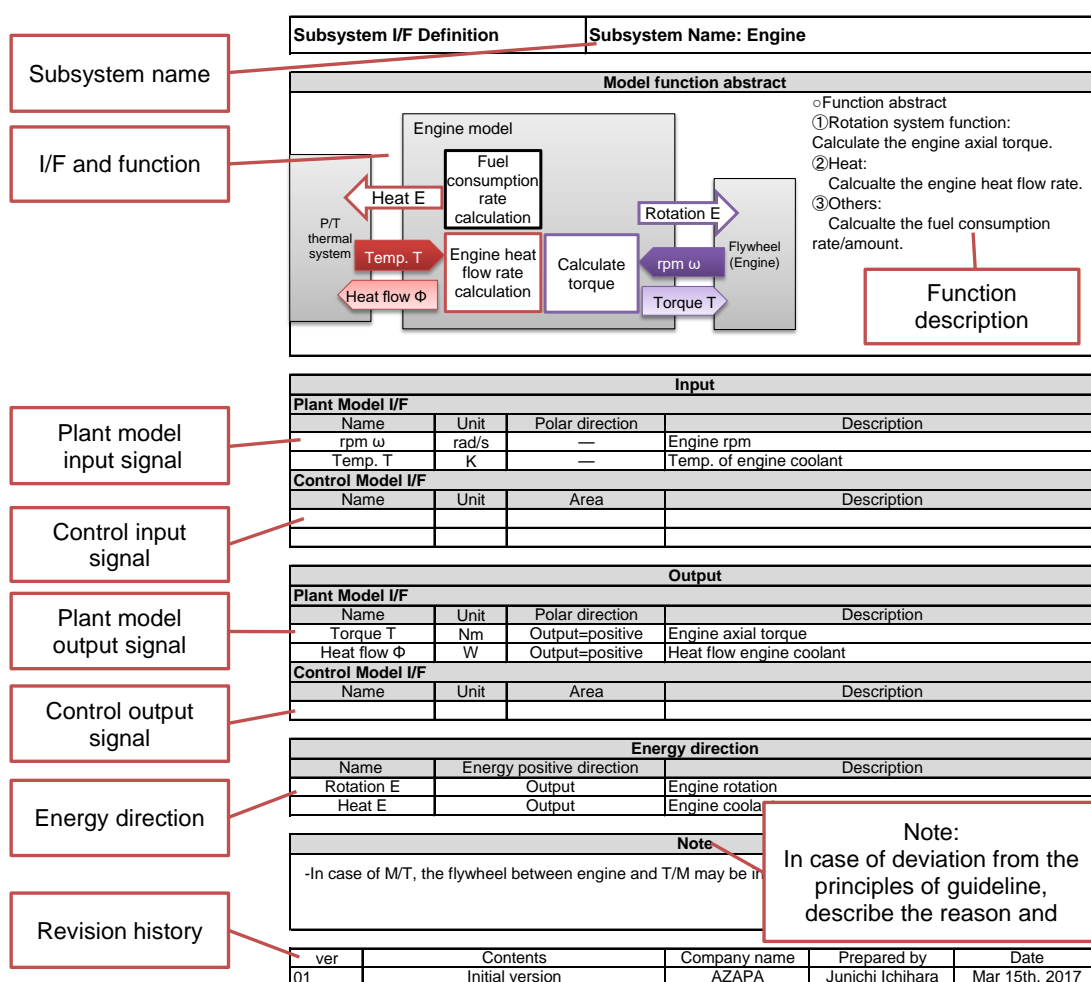


Fig. 23 Example of subsystem I/F definition document

Initial version of subsystem I/F definition document are shown below as examples:

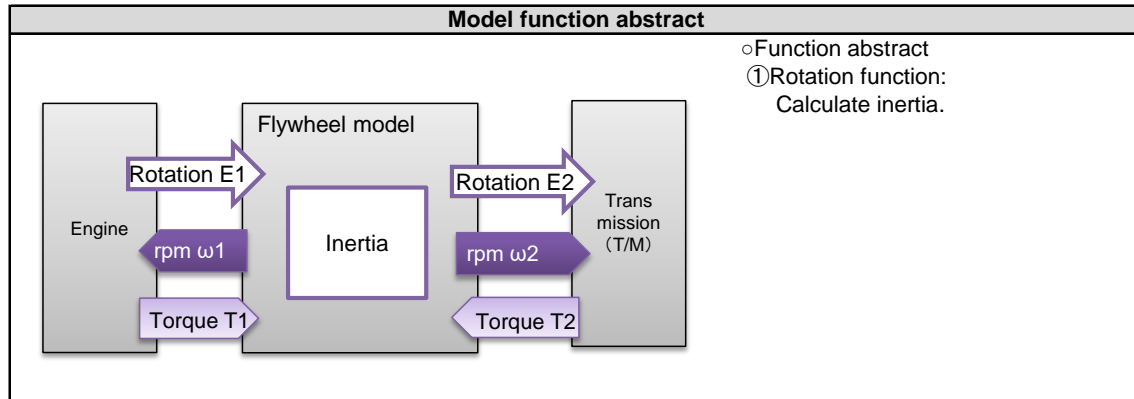
### 3. Example of subsystem definition document (fuel consumption)

#### (1) Engine model (power source model of mechanical system)

Subsystem I/F Definition		Subsystem Name: Engine																										
<div><div>Model function abstract</div><div><div><div><div><div><div>Heat E</div><div>Temp. T</div><div>Heat flow <math>\Phi</math></div></div><div><div>Engine model</div><div><div>Fuel consumption rate calculation</div><div>Engine heat flow rate calculation</div><div>Calculate torque</div></div><div><div>Rotation E</div><div>rpm <math>\omega</math></div><div>Torque T</div></div></div><div><div>P/T thermal system</div><div>Flywheel (Engine)</div></div></div></div><div><div>Function abstract</div><div><div>①Rotation system function: Calculate the engine axial torque.</div><div>②Heat: Calcualte the engine heat flow rate.</div><div>③Others: Calcualte the fuel consumption rate/amount.</div></div></div></div></div></div>																												
<div><div>Input</div><div><div>Plant Model I/F</div><table><tr><th>Name</th><th>Unit</th><th>Polar direction</th><th>Description</th></tr><tr><td>rpm <math>\omega</math></td><td>rad/s</td><td>—</td><td>Engine rpm</td></tr><tr><td>Temp. T</td><td>K</td><td>—</td><td>Temp. of engine coolant</td></tr></table><div><div>Control Model I/F</div><table><tr><th>Name</th><th>Unit</th><th>Area</th><th>Description</th></tr><tr><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td></tr></table></div></div></div>					Name	Unit	Polar direction	Description	rpm $\omega$	rad/s	—	Engine rpm	Temp. T	K	—	Temp. of engine coolant	Name	Unit	Area	Description								
Name	Unit	Polar direction	Description																									
rpm $\omega$	rad/s	—	Engine rpm																									
Temp. T	K	—	Temp. of engine coolant																									
Name	Unit	Area	Description																									
<div><div>Output</div><div><div>Plant Model I/F</div><table><tr><th>Name</th><th>Unit</th><th>Polar direction</th><th>Description</th></tr><tr><td>Torque T</td><td>Nm</td><td>Output=positive</td><td>Engine axial torque</td></tr><tr><td>Heat flow <math>\Phi</math></td><td>W</td><td>Output=positive</td><td>Heat flow engine coolant</td></tr></table><div><div>Control Model I/F</div><table><tr><th>Name</th><th>Unit</th><th>Area</th><th>Description</th></tr><tr><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td></tr></table></div></div></div>					Name	Unit	Polar direction	Description	Torque T	Nm	Output=positive	Engine axial torque	Heat flow $\Phi$	W	Output=positive	Heat flow engine coolant	Name	Unit	Area	Description								
Name	Unit	Polar direction	Description																									
Torque T	Nm	Output=positive	Engine axial torque																									
Heat flow $\Phi$	W	Output=positive	Heat flow engine coolant																									
Name	Unit	Area	Description																									
<div><div>Energy direction</div><table><tr><th>Name</th><th>Energy positive direction</th><th>Description</th></tr><tr><td>Rotation E</td><td>Output</td><td>Engine rotation</td></tr><tr><td>Heat E</td><td>Output</td><td>Engine coolant</td></tr></table></div>					Name	Energy positive direction	Description	Rotation E	Output	Engine rotation	Heat E	Output	Engine coolant															
Name	Energy positive direction	Description																										
Rotation E	Output	Engine rotation																										
Heat E	Output	Engine coolant																										
<div><div>Note</div><div>-In case of M/T, the flywheel between engine and T/M may be incorporated.</div></div>																												
ver	Contents	Company name	Prepared by	Date																								
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2017																								

## (2) Flywheel model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name: Flywheel</b>
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Input			
Name	Unit	Polar direction	Description
Torque T1	Nm	Input side = positive	Engine axial torque
Torque T2	Nm	Input side = positive	Engine torque from T/M
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
rpm $\omega_1$	rad/s	—	rpm of engine
rpm $\omega_2$	rad/s	—	rpm of engine
Name	Unit	Area	Description

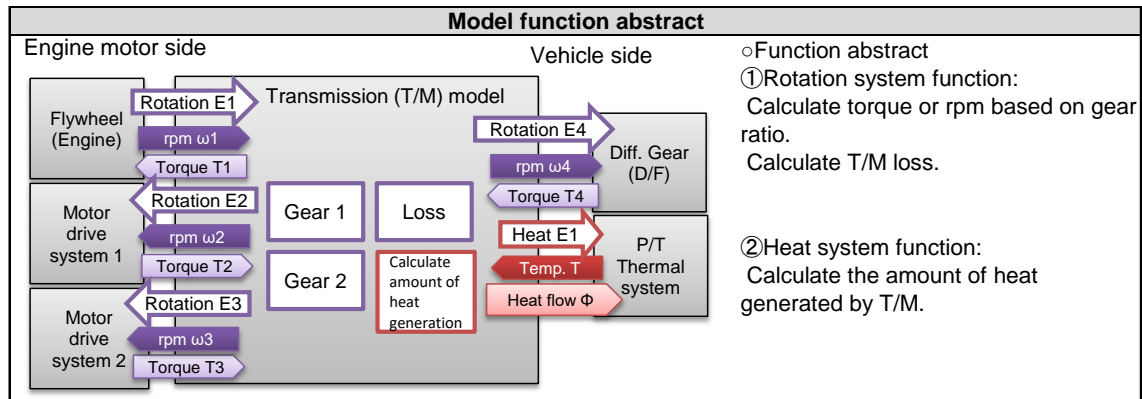
Energy direction		
Name	Energy positive direction	Description
Rotation E1	Input	Energy from Engine
Rotation E2	Output	Energy to T/M

Note	
<p>-In case of M/T, the flywheel may be incorporated into engine.            -In case of AT or CVT, the flywheel may be incorporated into transmission .</p>	

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### (3) Transmission model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name: Transmission</b>
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Input			
Name	Unit	Polar direction	Description
rpm $\omega_1$	rad/s	—	Engine rpm
Torque T2	Nm	Input side = positive	Motor drive system 1 Torque
Torque T3	Nm	Input side = positive	Motor drive system 2 Torque
Torque T4	Nm	Input side = positive	Torque between T/M and D/F
Temp. T	K	—	Temp. of coolant for P/T thermal system
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Torque T1	Nm	Output side=positive	Torque to engine axis
rpm $\omega_2$	rad/s	—	rpm of motor drive system 1
rpm $\omega_3$	rad/s	—	rpm of motor drive system 2
rpm $\omega_4$	rad/s	—	rpm between T/M and D/F
Heat flow $\Phi$	W	Output side=positive	Heat flow of coolant for P/T thermal system
Name	Unit	Area	Description

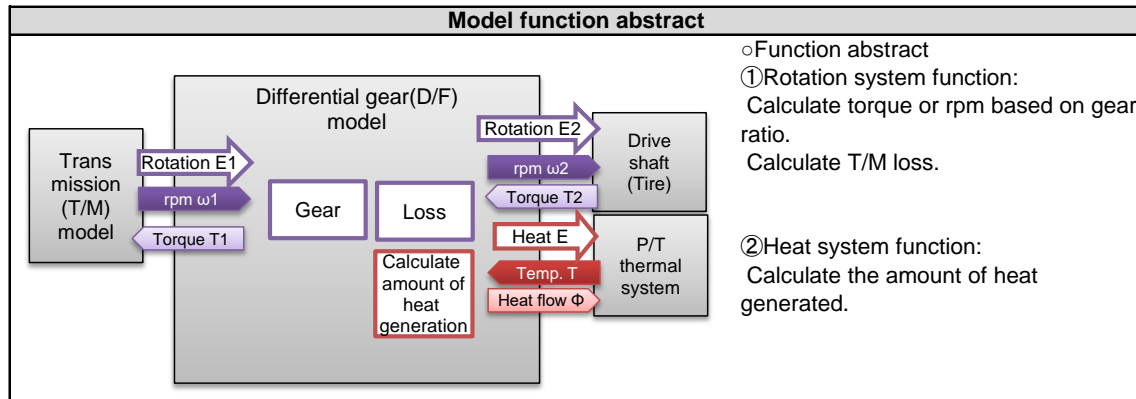
Energy direction		
Name	Energy positive direction	Description
Rotation E1	Input to model	Engine rotation
Rotation E2	Output from model	Motor drive system 1 rotation
Rotation E3	Output from model	Motor drive system 2 rotation
Rotation E4	Output from model	Rotation between T/M and D/F
Heat E	Output from model	Heat to P/T thermal system

Note	
-Assume a T/M for series parallel hybrid. -In case of A/T or CVT, ignore the part of motor drive system. -In case of A/T or CVT, the flywheel between engine and T/M may be incorporated.	

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#### (4) Differential gear model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name: Differential gear</b>
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Input			
Name	Unit	Polar direction	Description
rpm $\omega_1$	rad/s	—	Rotation T/M and D/F
Torque T2	Nm	Input side = positive	Torque to tire
Temp. T	K	—	Temp. of coolant to P/T thermal system
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Torque T1	Nm	Output side=positive	Torque of T/M
rpm $\omega_2$	rad/s	—	Rotation between D/F and tires
Heat flow $\Phi$	W	Output side=positive	Heat flow of coolant to P/T thermal system
Name	Unit	Area	Description

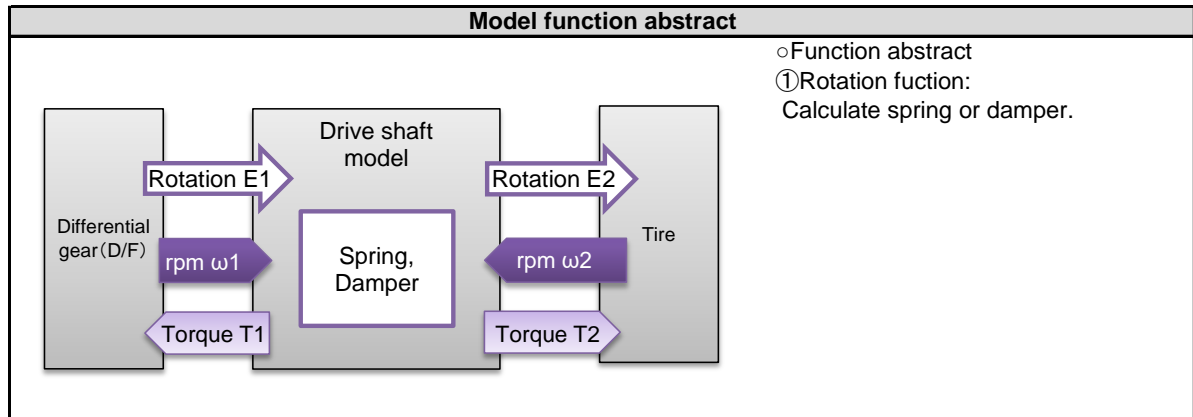
Energy direction		
Name	Energy positive direction	Description
Rotation E1	Input to model	T/M rotation
Rotation E2	Output from model	Rotation to tire
Heat E	Output from model	Heat to P/T thermal system

Note

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(5) Drive shaft model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name: Drive shaft</b>
---------------------------------	------------------------------------



Input			
Name	Unit	Polar direction	Description
rpm $\omega_1$	rad/s	—	rpm of drive shaft
rpm $\omega_2$	rad/s	—	rpm of drive shaft
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Torque T1	Nm	Output side=positive	Torque of differential gear
Torque T2	Nm	Output side=positive	Torque of tire
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Rotation E1	Input	Energy of differential gear
Rotation E2	Output	Energy of tire

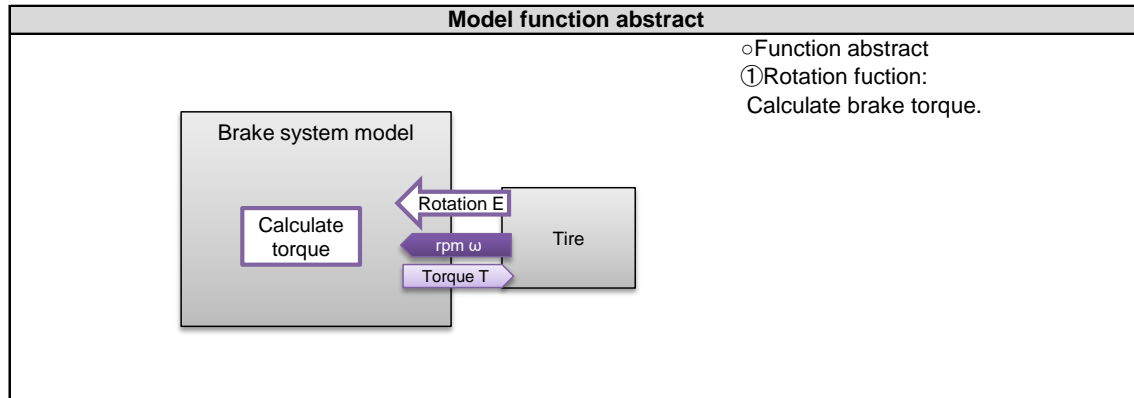
Note

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## (6) Brake system model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name : Brake system</b>
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Input			
Name	Unit	Polar direction	Description
rpm $\omega$	rad/s	—	Tire rpm
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Torque T	Nm	Output side=positive	T/M torque
Name	Unit	Area	Description

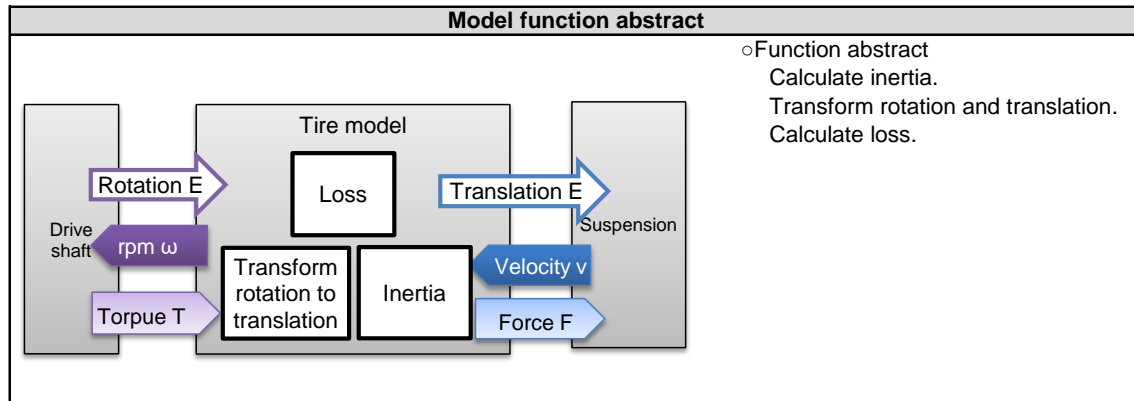
Energy direction		
Name	Energy positive direction	Description
Rotation E	Input	Energy of brake system

Note

ver	Contents	Company name	Prepared by	Date
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## (7) Tire model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name: Tire</b>
---------------------------------	-----------------------------



Input			
Name	Unit	Polar direction	Description
Torque T	Nm	Input side = positive	Torque of tire
Velocity v	m/s	—	Translation velocity of tire
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
rpm ω	rad/s	—	rpm of tire
Force F	N	Output side=positive	Force of tire driving
Name	Unit	Area	Description

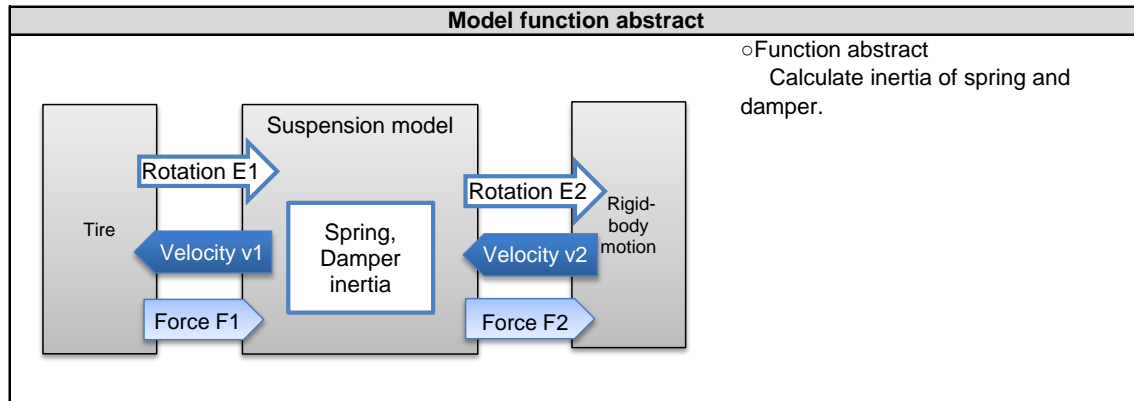
Energy direction		
Name	Energy positive direction	Description
Rotation E	Input	Energy from drive shaft
Translation E	Output	Energy to vehicle

Note	

ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2017

## (8) Suspension model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name: Suspension</b>
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Input			
Name	Unit	Polar direction	Description
Force F1	N	Input side = positive	Force from tire
Velocity v2	m/s	—	Vehicle velocity
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Velocity v1	m/s	—	Translation velocity of suspension
Force F2	N	Output side=positive	Force from vehicle
Name	Unit	Area	Description

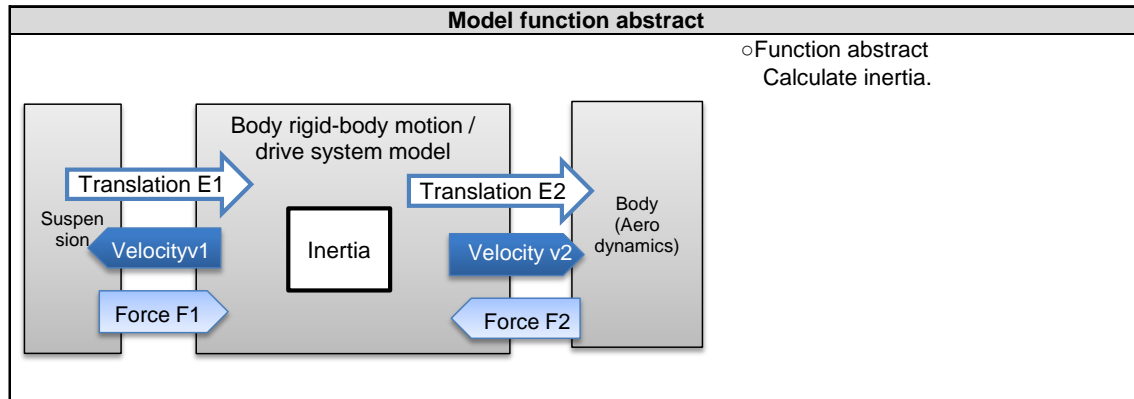
Energy direction		
Name	Energy positive direction	Description
Translation E1	Input	Energy from tire
Translation E2	Output	Energy to rigid-body motion

Note	

ver	Contents	Company name	Prepared by	Date
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## (9) Body rigid-body motion/drive system model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name: Body rigid-body motion / drive system</b>
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Input			
Name	Unit	Polar direction	Description
Force F1	N	Input side = positive	Force from suspension
Force F2	N	Input side = positive	Body loss
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Velocity v1	m/s	—	Vehicle velocity
Velocity v2	m/s	—	Vehicle velocity
Name	Unit	Area	Description

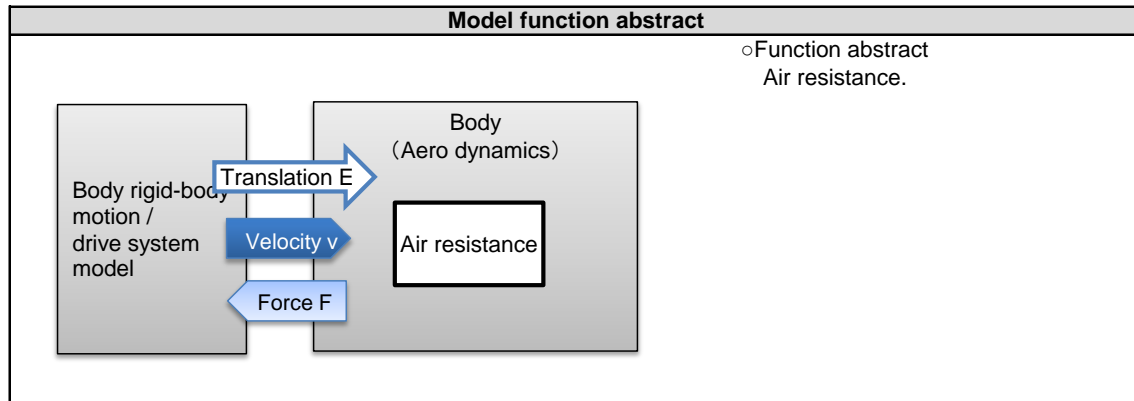
Energy direction		
Name	Energy positive direction	Description
Translation E1	Input	Energy from suspension
Translation E2	Output	Energy to body

Note	

ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2017

(10) Body (air resistance) model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name: Body</b>
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Input			
Name	Unit	Polar direction	Description
Velocity v	m/s	—	Vehicle velocity
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Force F	N	Output side=positive	Body loss
Name	Unit	Area	Description

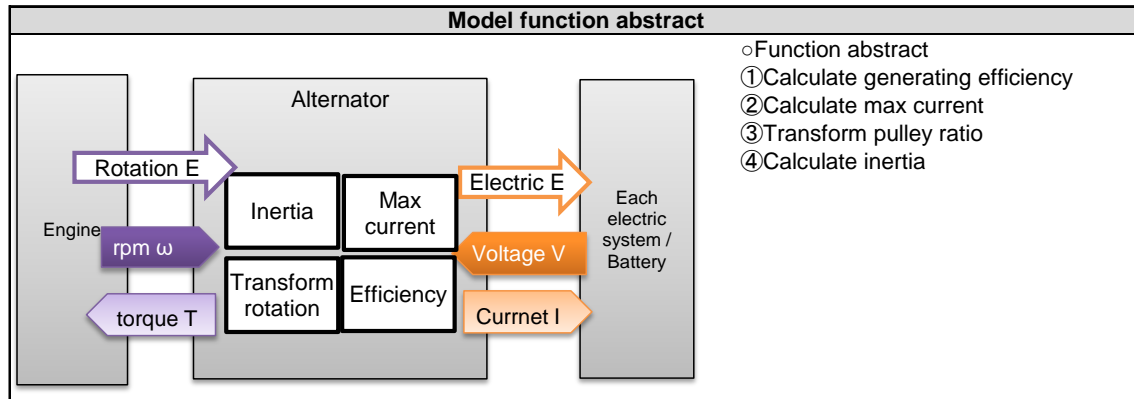
Energy direction		
Name	Energy positive direction	Description
Translation E2	Input	Energy to body

Note

ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2017

## (11) Alternator model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name: Alternator</b>
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Input			
Name	Unit	Polar direction	Description
rpm $\omega$	rad/s	—	Engine rpm
Voltage V	V	—	Alternator voltage
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Torque T	Nm	Output side=positive	Alternator torque of engine axis
Current I	A	Output side=positive	Current generated by alternator
Name	Unit	Area	Description

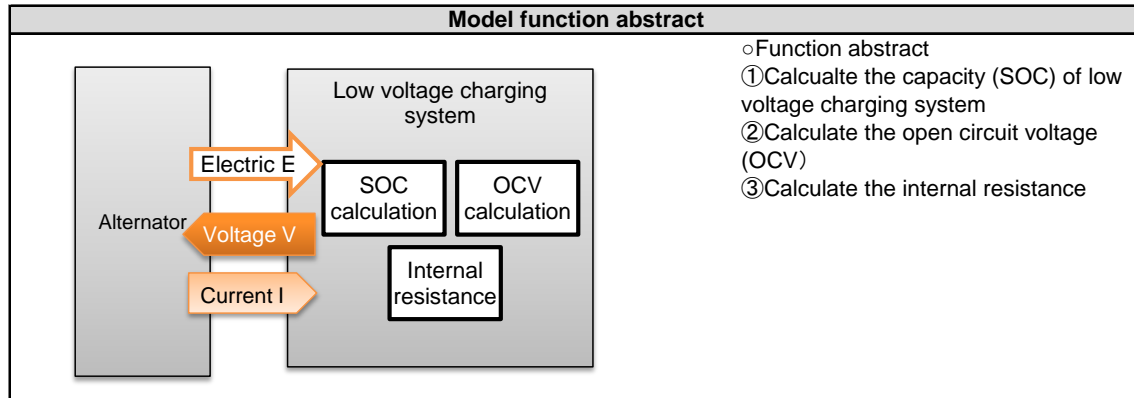
Energy direction		
Name	Energy positive direction	Description
Rotation E	Input	Energy from engine
Electric E	Output	Energy from alternator

Note

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## (12) Low voltage charging system model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name: Low voltage charging system</b>
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Input			
Name	Unit	Polar direction	Description
Current I	A	Input = positive	Current of Low voltage charging system
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Voltage V	V	—	Low voltage charging system
Name	Unit	Area	Description

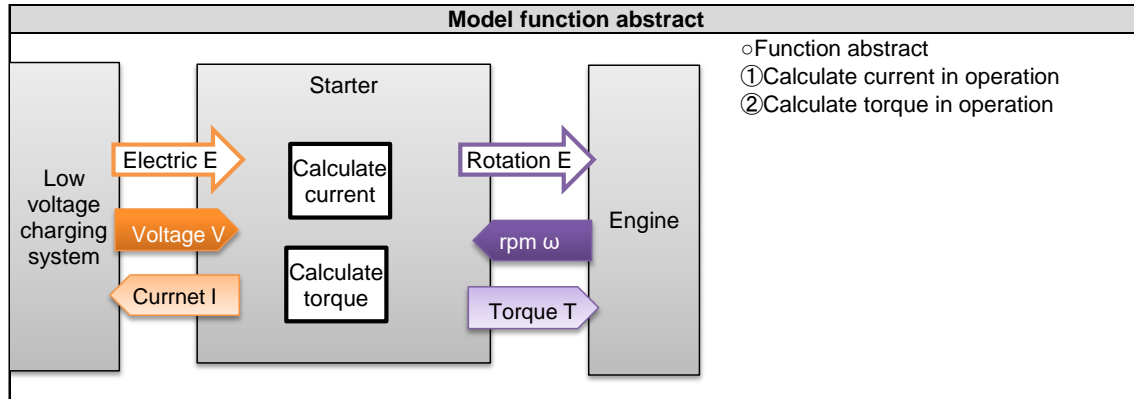
Energy direction		
Name	Energy positive direction	Description
Electric E	Input	Energy to low voltage charging system

Note

ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2017

### (13) Starter model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name: Starter</b>
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Input			
Name	Unit	Polar direction	Description
Voltage V	V	—	Low voltage charging system
rpm $\omega$	rad/s	—	Engine rpm
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Current I	A	Output side=positive	Current of starter
Torque T	Nm	Output side=positive	Starter torque
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Electric E	Input	Electric energy of starter
Rotation E	Output	Drive energy of starter

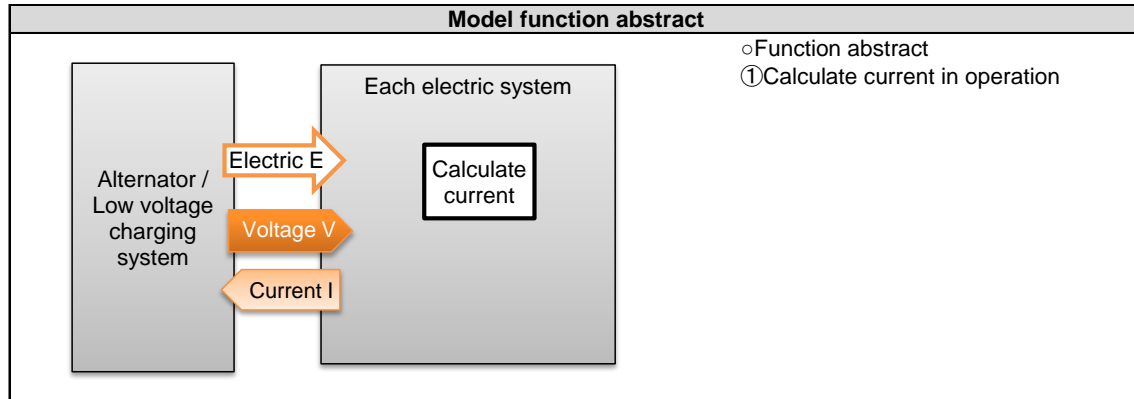
Note

ver	Contents	Company name	Prepared by	Date
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(14) Model of each electric system

<b>Subsystem I/F Definition</b>	<b>Subsystem Name: Each electric system</b>
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Input			
Name	Unit	Polar direction	Description
Voltage V	V	—	Low voltage charging system
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Current I	A	Output side=positive	Current of each electric system
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Electric E	Input	Energy of each electric system

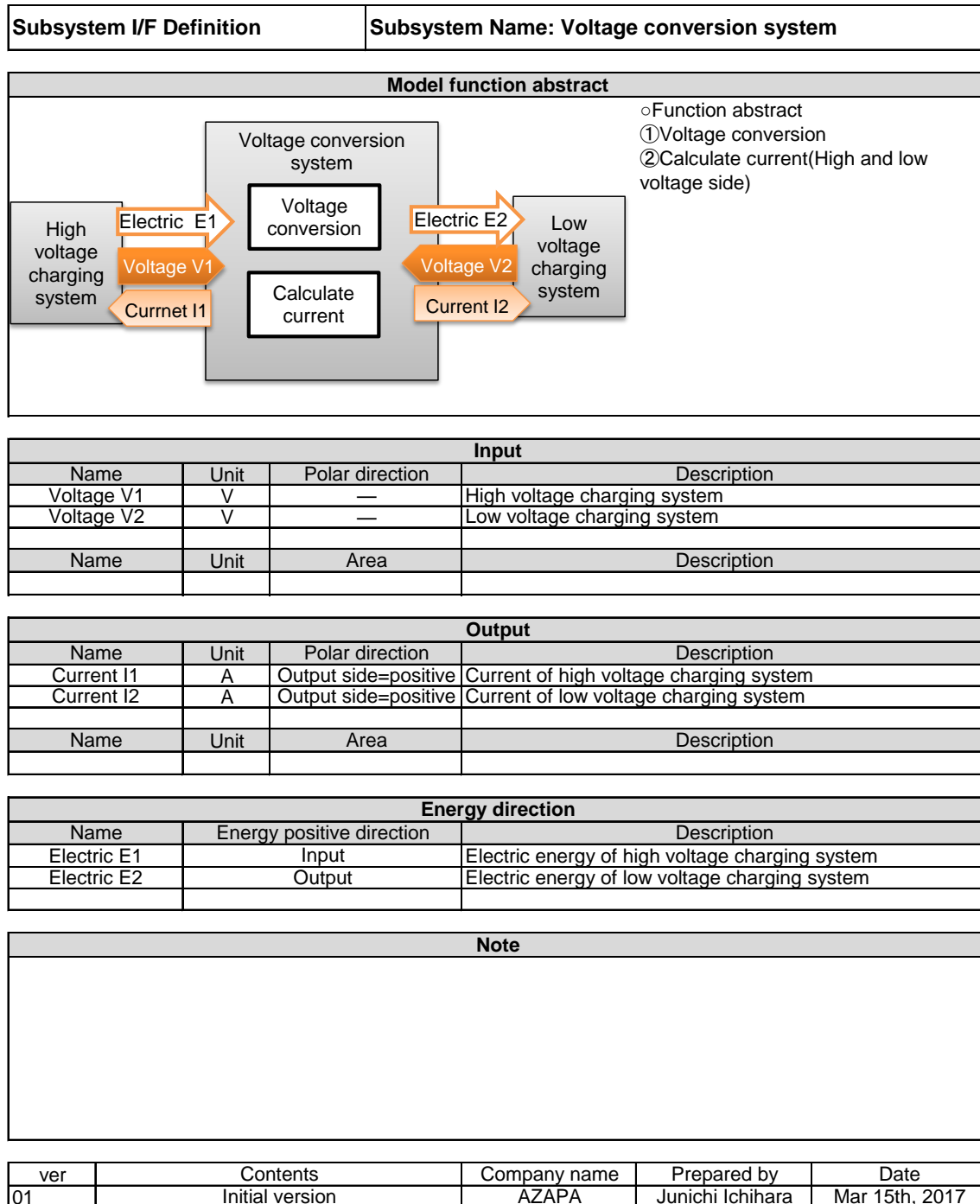
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ver	Contents	Company name	Prepared by	Date
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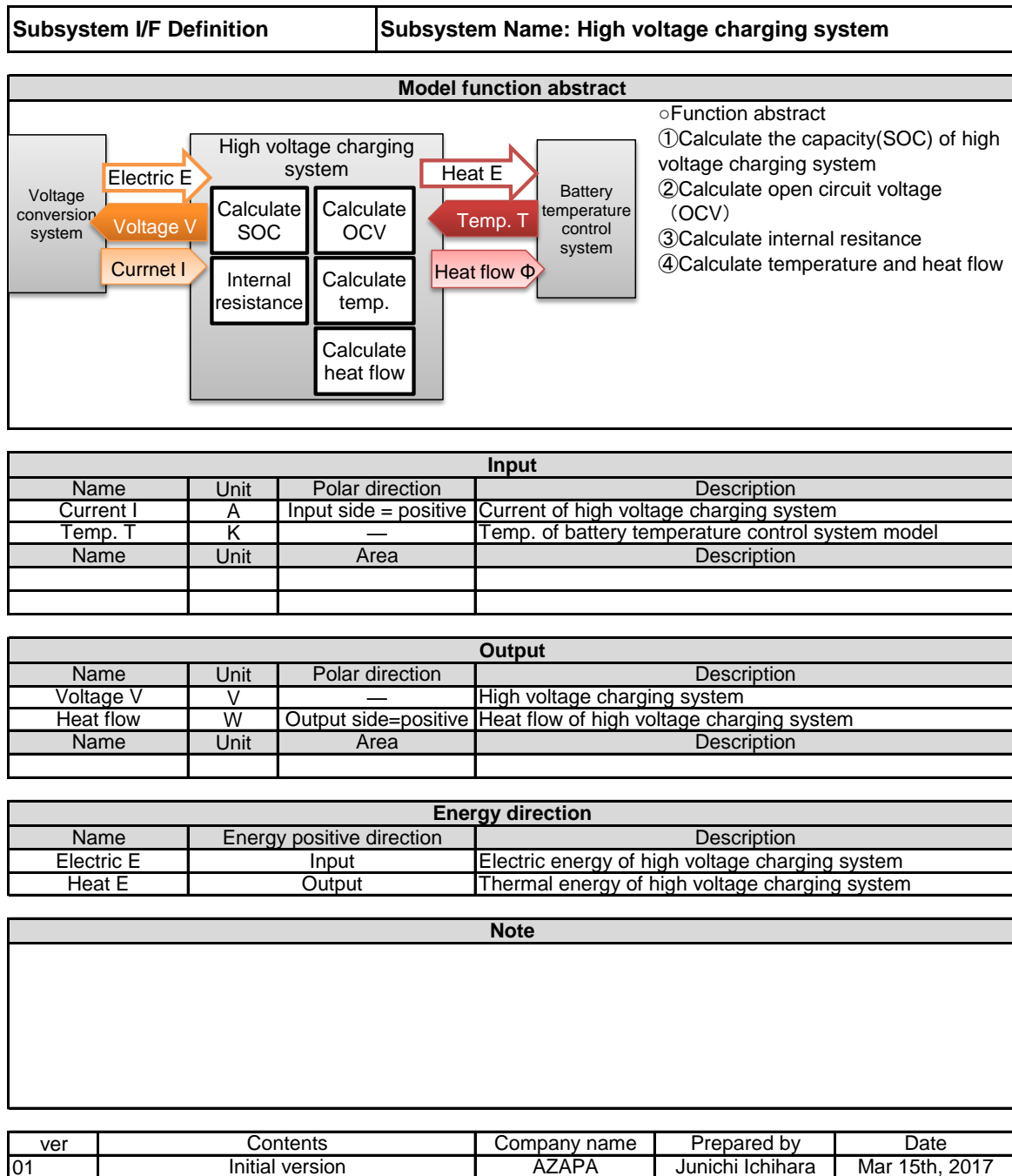
### (15) Battery temperature control system model

Subsystem I/F Definition		Subsystem Name: Battery temperature control system		
Model function abstract				
		○Function abstract ①Calculate current in operation ②Calculate heat capacity in operation ③Calculate heat capacity of battery temperature control system		
Input				
Name	Unit	Polar direction	Description	
VoltageV	V	—	Low voltage charging system	
Heat flow Φ1	W	Input side = positive	Heat flow from high voltage charging system	
Temp. T2	K	—	Temp. of heatsink	
Name	Unit	Area	Description	
Output				
Name	Unit	Polar direction	Description	
Current I	A	Output side=positive	Current of battery temperature control system	
Temp. T1	K	—	Temp. of battery temperature control system	
Heat flow Φ2	W	Output side=positive	Heat flow to heatsink	
Name	Unit	Area	Description	
Energy direction				
Name	Energy positive direction		Description	
Electric E	Input		Electric energy of battery temperature control system	
Heat E1	Input		Thermal energy from high voltage charging system	
Heat E2	Output		Thermal energy to heatsink	
Note				
ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th. 2017

(16) Voltage conversion system model

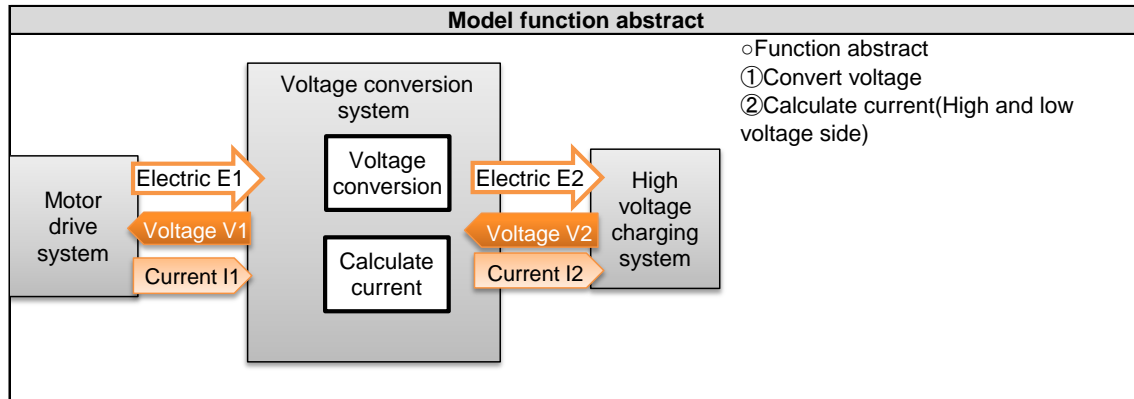


# (17) High voltage charging system model



(18) Voltage conversion system (pressurization) model

Subsystem I/F Definition	Subsystem Name : Voltage conversion system (pressurization)
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Input			
Name	Unit	Polar direction	Description
Current I1	A	Input side = positive	Current (High voltage side)
Voltage V2	V	—	Voltage (Low voltage side)
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Voltage V1	V	—	Voltage (High voltage side)
Current I2	A	Output side=positive	Current (Low voltage side)
Name	Unit	Area	Description

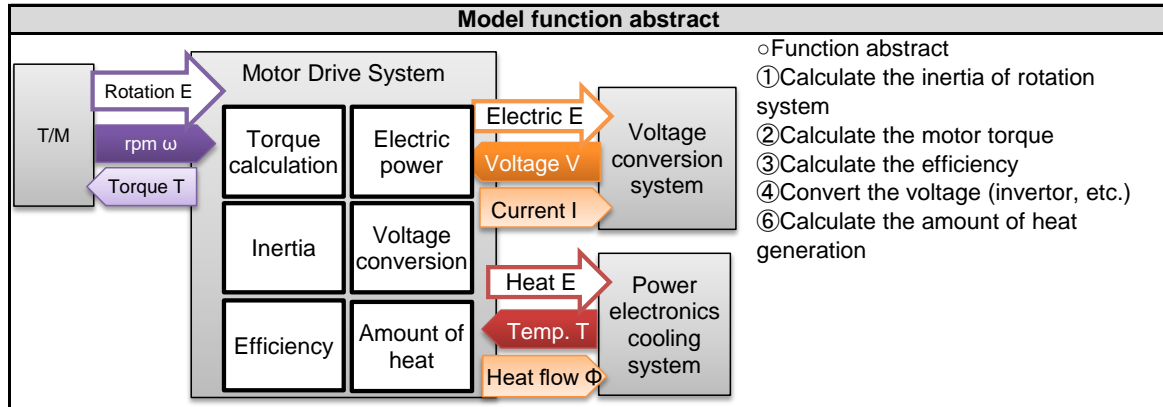
Energy direction		
Name	Energy positive direction	Description
Electric E1	Input	Electric energy (High voltage side)
Electric E2	Output	Electric energy (Low voltage side)

Note

ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2017

(19) Motor drive system model

Subsystem I/F Definition	Subsystem name : Motor drive system
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Input			
Name	Unit	Polar direction	Description
rpm $\omega$	rad/s	—	rpm of motor drive system
Voltage V	V	—	Input voltage of motor drive system
Temp. T	K	—	Temp. of coolant
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Torque T	Nm	Output side=positive	Torque of motor drive system
Current I	A	Output side=positive	Input current of motor drive system
Heat flow $\Phi$	W	Output side=positive	Heat flow to coolant
Name	Unit	Area	Description

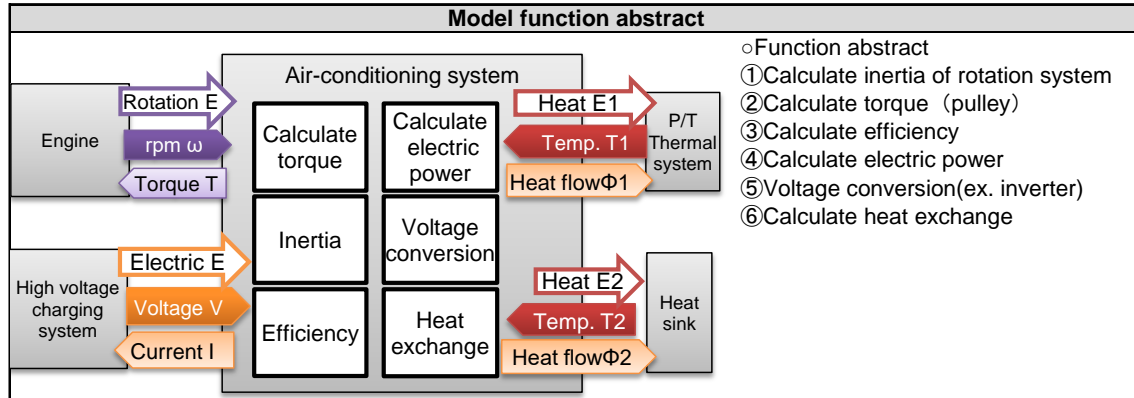
Energy direction		
Name	Energy positive direction	Description
Rotation E	Input	Rotation energy of motor drive system
Electric E	Output	Electric energy of motor drive system
Heat E	Output	Thermal energy of motor drive system

Note

ver	Contents	Company name	Prepared by	Date
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## (20) Air-conditioning system Model

Subsystem I/F Definition	Subsystem Name : Air-conditioning system
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Input			
Name	Unit	Polar direction	Description
rpm $\omega$	rad/s	—	Engine rpm
Voltage V	V	—	High voltage charging system
Temp. T1	K	—	Temp. of coolant
Temp. T2	K	—	Temp. of heatsink
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Torque T	Nm	Output side=positive	Torque of air-conditioning system to engine
Current I	A	Output side=positive	Required current for air-conditioning system
Heat flow $\Phi 1$	W	Output side=positive	Heat flow to coolant
Heat flow $\Phi 2$	W	Output side=positive	Heat flow to heatsink
Name	Unit	Area	Description

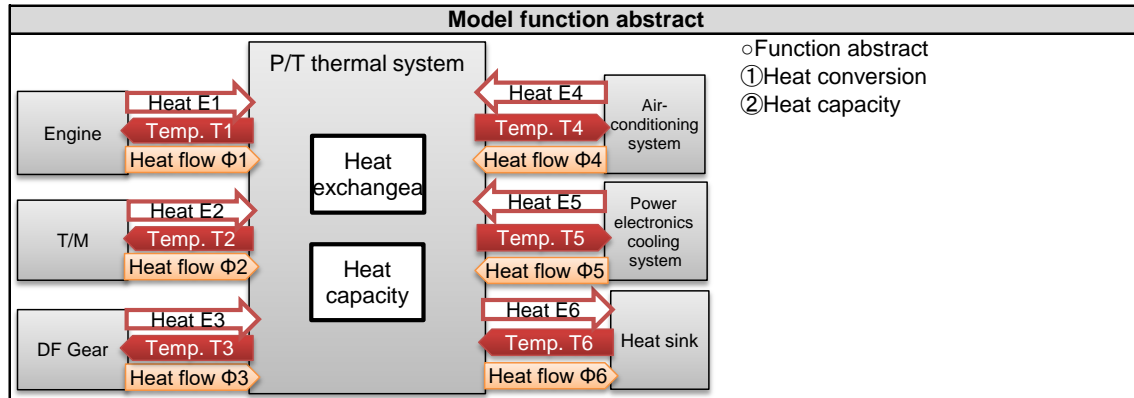
Energy direction		
Name	Energy positive direction	Description
Rotation E	Input	Rotation energy of air-conditioning system
Electric E	Input	Electric energy of air-conditioning system
Heat E1	Output	Thermal energy of air-conditioning system to P/T
Heat E2	Output	Thermal energy of air-conditioning system to heatsink

Note	

ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2017

## (21) P/T thermal System Model

<b>Subsystem I/F Definition</b>	<b>Subsystem name : P/T thermal system</b>
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Input			
Name	Unit	Polar direction	Description
Heat flow Φ1	W	Input side = positive	Heat flow from engine
Heat flow Φ2	W	Input side = positive	Heat flow from T/M
Heat flow Φ3	W	Input side = positive	Heat flow from differential gear
Heat flow Φ4	W	Input side = positive	Heat flow from air-conditioning system
Heat flow Φ5	W	Input side = positive	Heat flow from power electronics cooling system
Temp. T6	K	—	Temp. of heatsink
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Temp. T1	K	—	Temp. of P/T thermal system
Temp. T2	K	—	Temp. of P/T thermal system
Temp. T3	K	—	Temp. of P/T thermal system
Temp. T4	K	—	Temp. of P/T thermal system
Temp. T5	K	—	Temp. of P/T thermal system
Heat flow Φ6	W	Output side=positive	Heat flow to heatsink
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Heat E1	Input	Energy from engine
Heat E2	Input	Energy from T/M
Heat E3	Input	Energy from differential gear
Heat E4	Input	Energy from air-conditioning system
Heat E5	Input	Energy from power electronics cooling system
Heat E6	Output	Thermal energy to heatsink

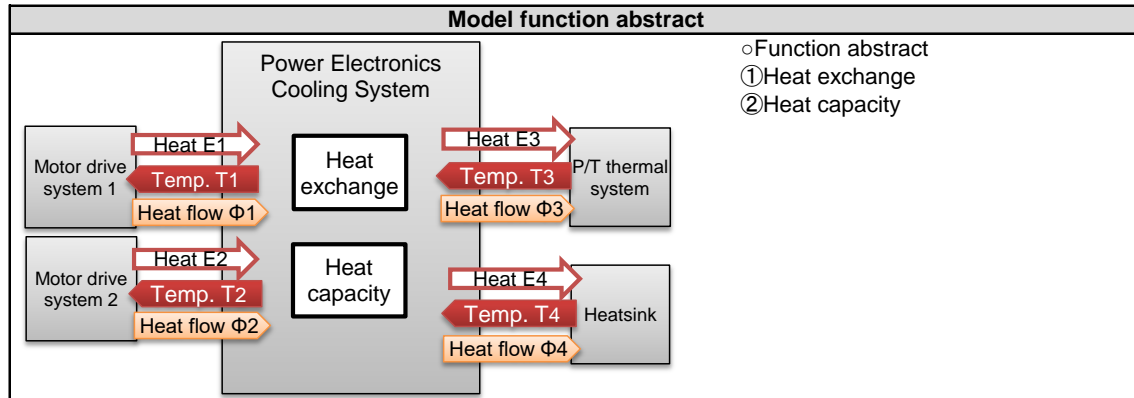
Note

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## (22) Power Electronics Cooling System Model

<b>Subsystem I/F Definition</b>	<b>Subsystem Name : Power electronics cooling system</b>
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Input			
Name	Unit	Polar direction	Description
Heat flow $\Phi 1$	W	Input side = positive	Heat flow from motor drive system 1
Heat flow $\Phi 2$	W	Input side = positive	Heat flow from motor drive system 2
Temp. T3	K	—	Temp. of P/T thermal system
Temp. T4	K	—	Temp. of heatsink
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Temp. T1	K	—	Temp. of power electronics cooling system
Temp. T2	K	—	Temp. of power electronics cooling system
Heat flow $\Phi 3$	W	Output side=positive	Heat flow to P/T thermal system
Heat flow $\Phi 4$	W	Output side=positive	Heat flow to heatsink
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Heat E1	Input	Energy from motor drive system 1
Heat E2	Input	Energy from motor drive system 2
Heat E3	Output	Energy to P/T thermal system
Heat E4	Output	Thermal energy to heatsink

Note	

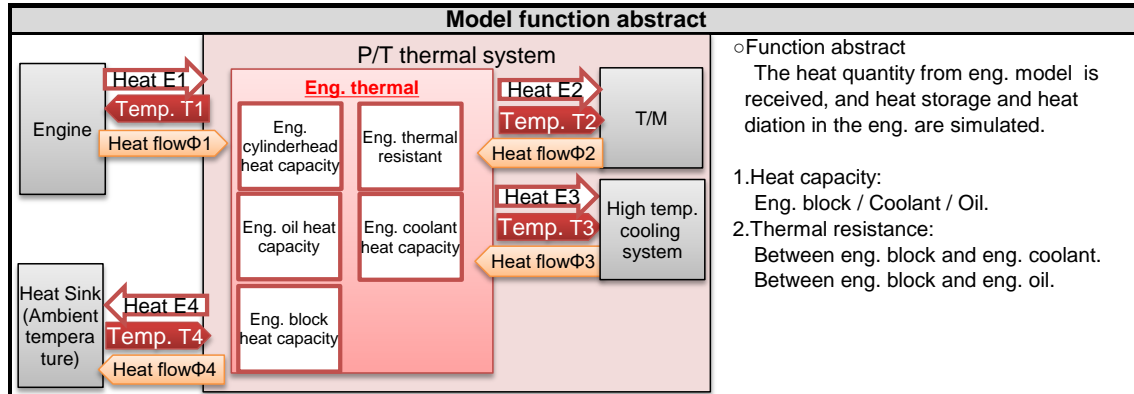
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01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2017

## (23) Heat Sink Model

Subsystem I/F Definition		Subsystem Name : Heatsink																																						
Model function abstract																																								
			○Function abstract ①Heat exchange ②Heat capacity																																					
<table><tr><th colspan="4">Input</th></tr><tr><th>Name</th><th>Unit</th><th>Polar direction</th><th>Description</th></tr><tr><td>Heat flow Φ1</td><td>W</td><td>Input side = positive</td><td>Heat flow from P/T thermal system</td></tr><tr><td>Heat flow Φ2</td><td>W</td><td>Input side = positive</td><td>Heat flow from power electronics cooling system</td></tr><tr><td>Heat flow Φ3</td><td>W</td><td>Input side = positive</td><td>Heat flow from air-conditioning system</td></tr><tr><td>Heat flow Φ4</td><td>W</td><td>Input side = positive</td><td>Heat flow from battery temperature control system</td></tr><tr><td> </td><td> </td><td> </td><td> </td></tr><tr><th>Name</th><th>Unit</th><th>Area</th><th>Description</th></tr><tr><td> </td><td> </td><td> </td><td> </td></tr></table>					Input				Name	Unit	Polar direction	Description	Heat flow Φ1	W	Input side = positive	Heat flow from P/T thermal system	Heat flow Φ2	W	Input side = positive	Heat flow from power electronics cooling system	Heat flow Φ3	W	Input side = positive	Heat flow from air-conditioning system	Heat flow Φ4	W	Input side = positive	Heat flow from battery temperature control system					Name	Unit	Area	Description				
Input																																								
Name	Unit	Polar direction	Description																																					
Heat flow Φ1	W	Input side = positive	Heat flow from P/T thermal system																																					
Heat flow Φ2	W	Input side = positive	Heat flow from power electronics cooling system																																					
Heat flow Φ3	W	Input side = positive	Heat flow from air-conditioning system																																					
Heat flow Φ4	W	Input side = positive	Heat flow from battery temperature control system																																					
Name	Unit	Area	Description																																					
<table><tr><th colspan="4">Output</th></tr><tr><th>Name</th><th>Unit</th><th>Polar direction</th><th>Description</th></tr><tr><td>Temp. T1</td><td>K</td><td>—</td><td>Temp. of heatsink</td></tr><tr><td>Temp. T2</td><td>K</td><td>—</td><td>Temp. of heatsink</td></tr><tr><td>Temp. T3</td><td>K</td><td>—</td><td>Temp. of heatsink</td></tr><tr><td>Temp. T4</td><td>K</td><td>—</td><td>Temp. of heatsink</td></tr><tr><td> </td><td> </td><td> </td><td> </td></tr><tr><th>Name</th><th>Unit</th><th>Area</th><th>Description</th></tr><tr><td> </td><td> </td><td> </td><td> </td></tr></table>					Output				Name	Unit	Polar direction	Description	Temp. T1	K	—	Temp. of heatsink	Temp. T2	K	—	Temp. of heatsink	Temp. T3	K	—	Temp. of heatsink	Temp. T4	K	—	Temp. of heatsink					Name	Unit	Area	Description				
Output																																								
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Temp. T1	K	—	Temp. of heatsink																																					
Temp. T2	K	—	Temp. of heatsink																																					
Temp. T3	K	—	Temp. of heatsink																																					
Temp. T4	K	—	Temp. of heatsink																																					
Name	Unit	Area	Description																																					
<table><tr><th colspan="3">Energy direction</th></tr><tr><th>Name</th><th>Energy positive direction</th><th>Description</th></tr><tr><td>Heat E1</td><td>Input</td><td>Energy from P/T thermal system</td></tr><tr><td>Heat E2</td><td>Input</td><td>Energy from power electronics cooling system</td></tr><tr><td>Heat E3</td><td>Input</td><td>Energy from air-conditioning system</td></tr><tr><td>Heat E4</td><td>Input</td><td>Energy from battery temperature control system</td></tr><tr><td> </td><td> </td><td> </td></tr></table>					Energy direction			Name	Energy positive direction	Description	Heat E1	Input	Energy from P/T thermal system	Heat E2	Input	Energy from power electronics cooling system	Heat E3	Input	Energy from air-conditioning system	Heat E4	Input	Energy from battery temperature control system																		
Energy direction																																								
Name	Energy positive direction	Description																																						
Heat E1	Input	Energy from P/T thermal system																																						
Heat E2	Input	Energy from power electronics cooling system																																						
Heat E3	Input	Energy from air-conditioning system																																						
Heat E4	Input	Energy from battery temperature control system																																						
Note																																								

## (24) Engine Model (P/T thermal)

<b>Subsystem I/F Definition</b>	<b>Subsystem Name = Eng. (P/T thermal)</b>	
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Input			
Plant model I/F			
Name	Unit	Polar direction	Description
Heat flowΦ1	W	Input side = positive	Heat flow from eng. heat source to eng. thermal
Heat flowΦ2	W	Input side = positive	Heat flow from eng. thermal to T/M
Heat flowΦ3	W	Input side = positive	Heat flow eng. thermal to high temp. cooling system
Temp.T4	K	—	Eng. block Temp.
Controller model I/F			
Name	Unit	Area	Description

Output			
Plant model I/F			
Name	Unit	Polar direction	Description
Temp.T1	K	—	Temp. of eng. cylinder head
Temp.T2	K	—	Temp. from eng. thermal to T/M
Temp.T3	K	—	Temp. of eng. coolant
Heat flowΦ4	W	Input side = positive	Heat flow from eng. block to heat sink
Controller model I/F			
Name	Unit	Area	Description

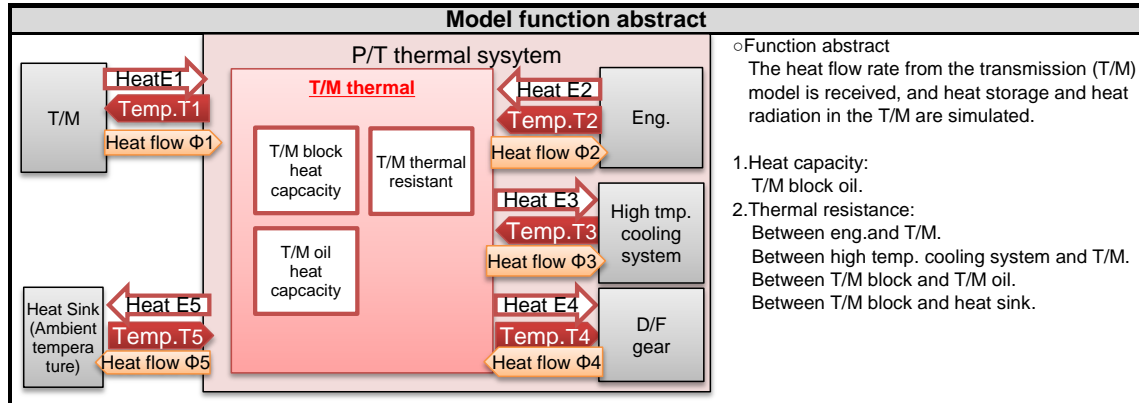
Energy direction		
Name	Energy positive direction	Description
Heat E1	Input	Energy from eng. heat source
Heat E2	Output	Thermal energy from eng. thermal to T/M
Heat E3	Output	Thermal energy from eng. thermal to high temp. cooling system
Heat E4	Output	Thermal energy from eng. thermal to heat sink

Note	
Although the energy I/F to the heat sink (ambient temperature) is one, there may be multiple I/Fs according to the verification contents.	

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01	Initial version	AZAPA	Junichi Ichihara	Mar 8th, 2019
02	Revised error	AZAPA	Junichi Ichihara	Nov 13th, 2019

## (25) Transmission Model (P/T thermal)

<b>Subsystem I/F Definition</b>	<b>Subsystem Name= Transmission (P/T thermal)</b>
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Input			
Plant model I/F			
Name	Unit	Polar direction	Description
Heat flow Φ1	W	Input side = positive	Heat flow from T/M heat source to T/M thermal
Temp.T2	K	—	Temp.from eng. thermal to T/M thermal
Temp.T3	K	—	Temp.from high temp. cooling system to T/M thermal
Heat flow Φ4	W	Input side = positive	Heat flow from T/M thermal to D/F thermal
Temp.T5	K	—	Heat sink temp.
Controller model I/F			
Name	Unit	Area	Description

Output			
Plant model I/F			
Name	Unit	Polar direction	Description
Temp.T1	K	—	T/M oil temp.
Heat flow Φ2	W	Input side = positive	Heat flow from eng. thermal to T/M thermal
Heat flow Φ3	W	Input side = positive	Heat flow from high temp. cooling system to T/M thermal
Temp.T4	K	—	Temp.of T/M block
Heat flow Φ5	W	Input side = positive	Heat flow to heat sink
Controller model I/F			
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Heat E1	Input	Thermal energy from T/M heat source to T/M thermal
Heat E2	Input	Thermal energy from eng. thermal to T/M thermal
Heat E3	Output	Thermal energy from high temp. cooling system to T/M thermal
Heat E4	Output	Thermal energy from T/M thermal to D/F thermal
Heat E5	Output	Thermal energy to heat sink

Note
Although the energy I/F to the heat sink (ambient temperature) is one, there may be multiple I/Fs according to the verification contents.

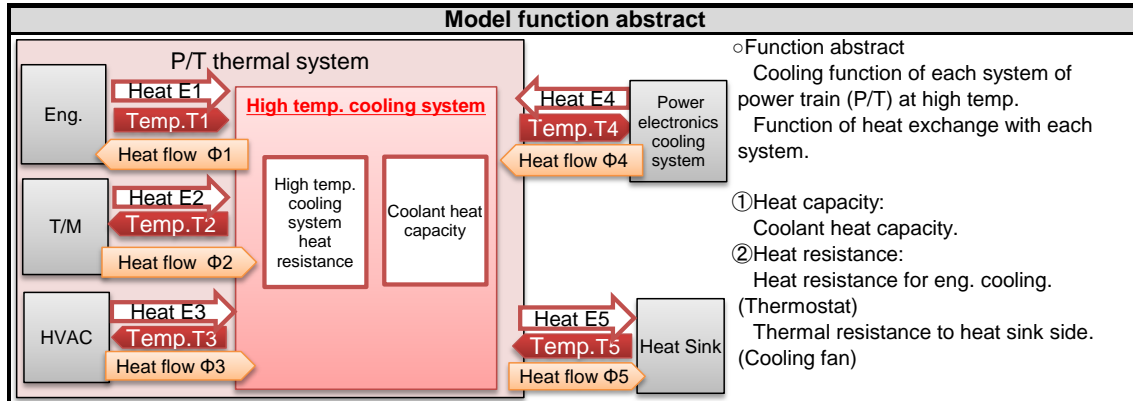
ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 8th, 2019
02	Revised error	AZAPA	Junichi Ichihara	Nov 13th, 2019

(26) Differential gear Model (P/T thermal)

Subsystem I/F Definition		Subsystem Name= Differential gear (P/T thermal)	
Model function abstract			
		<p>○Function abstract Heat flow from differential gear (D/F) model is received, and heat storage and heat radiation in the D/F are simulated.</p> <p>①Heat capacity: D/F block/oil.</p> <p>②Thermal resistance: Between D/F gear and T/M. Between high temp. cooling system and T/M. Between T/M block and T/M oil. Between T/M block and heat sink.</p>	
Input			
Plant model I/F			
Name	Unit	Polar direction	Description
Heat flowΦ1	W	Input side = positive	Heat flow from D/F heat source to D/F thermal
Temp.T2	K	—	D/F block Temp.
Temp.T3	K	—	Heat sink Temp.
Controller model I/F			
Name	Unit	Area	Description
Output			
Plant model I/F			
Name	Unit	Polar direction	Description
Temp.T1	K	—	D/F oil temp.
Heat flowΦ2	W	Output side = positive	Heat flow from D/F thermal to T/M thermal
Heat flowΦ3	W	Output side = positive	Heat flow to heat sink
Controller model I/F			
Name	Unit	Area	Description
Energy direction			
Name	Energy positive direction		Description
Heat E1	Input		Thermal energy from D/F heat source to D/F thermal
Heat E2	Input		Thermal energy from T/M thermal to D/F thermal
Heat E3	Output		Thermal energy to heat sink
Note			
Although the energy I/F to the heat sink (ambient temperature) is one, there may be multiple I/Fs according to the verification contents.			

## (27) High temperature cooling system Model (P/T thermal)

<b>Subsystem I/F Definition</b>	Subsystem Name= High temp. cooling system (P/T thermal)	
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Input			
Plant model I/F			
Name	Unit	Polar direction	Description
Temp.T1	K	—	Temp. of eng. coolant
Heat flowΦ2	W	Input side = positive	Heat quantity from T/M thermal to high temp. cooling system
Heat flowΦ3	W	Input side = positive	Temp. to HVAC thermal high temp. cooling system
Heat flowΦ4	W	Input side = positive	Heat flow from power electronics cooling system to high temp. cooling system
Temp.T5	K	—	Temp.of heat sink
Controller model I/F			
Name	Unit	Area	Description

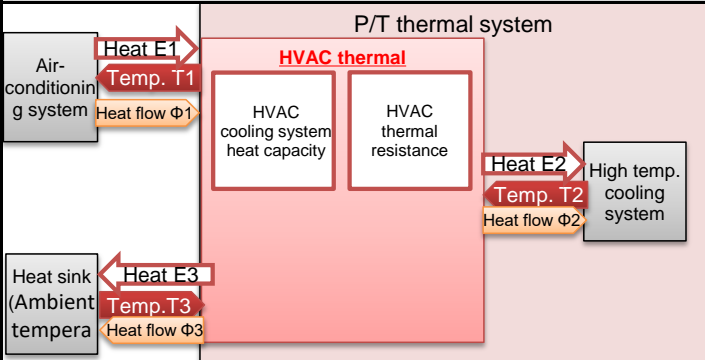
Output			
Plant model I/F			
Name	Unit	Polar direction	Description
Heat flowΦ1	W	Output side = positive	Heat quantity from Eng.thermal to high temp. cooling system
Temp.T2	K	—	Temp. from T/M thermal
Temp.T3	K	—	Temp.from HVAC thermal
Temp.T4	K	—	Temp. from power electronics cooling system
Heat flowΦ5	W	Output side = positive	Heat flow to heat sink
Controller model I/F			
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Heat E1	Input	Thermal energy from Eng.thermal to high temp. cooling system
Heat E2	Input	Thermal energy from T/M thermal to high temp. cooling system
Heat E3	Input	Thermal energy from HVAC thermal to high temp. cooling system
Heat E4	Input	Thermal energy from power electronics cooling system to high temp. cooling system
Heat E5	Output	Thermal energy to heat sink

Note
Although the energy I/F to the heat sink (ambient temperature) is one, there may be multiple I/Fs according to the verification contents.

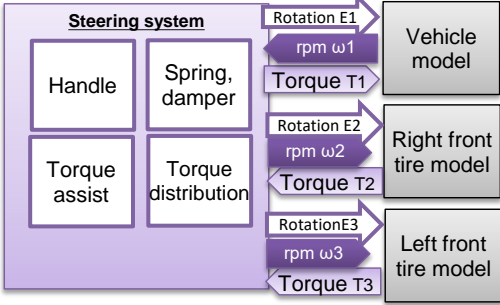
ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 8th, 2019

(28) HVAC Model (P/T thermal)

Subsystem I/F Definition		Subsystem Name= HVAC (P/T thermal)	
Model function abstract			
		<div>○Function abstract</div> <p>The heat flow rate from the air-conditioning system model is received, and heat exchange in HVAC thermal is performed.</p> <div>①Heat capacity: HVAC cooling system heat capacity.</div> <div>②Thermal resistance: Between air-conditioning system and HVAC thermal. Between high temp. cooling system and HVAC thermal. Between HVAC thermal and heat sink (outside air).</div>	
Input			
Plant model I/F			
Name	Unit	Polar direction	Description
Heat flowΦ1	W	Input side = positive	Heat flow from air-conditioning system to HVAC thermal
Temp.T2	K	—	Temp. from HVAC thermal to high temp. cooling system
Temp.T3	K	—	Heat sink temp.
Controller model I/F			
Name	Unit	Area	Description
Output			
Plant model I/F			
Name	Unit	Polar direction	Description
Temp.T1	K	—	HVAC thermal temp.
Heat flowΦ2	W	Output side = positive	Heat flow from HVAC thermal to high temp. cooling system
Heat flowΦ3	W	Output side = positive	Heat flow from HVAC thermal to heat sink
Controller model I/F			
Name	Unit	Area	Description
Energy direction			
Name	Energy positive direction		Description
Heat E1	Input		Thermal energy from air-conditioning system to HVAC thermal
Heat E2	Output		Thermal energy from HVAC thermal to high temp. cooling system
Heat E3	Output		Thermal energy from HVAC thermal to heat sink
Note			
Although the energy I/F to the heat sink (ambient temperature) is one, there may be multiple I/Fs according to the verification contents.			

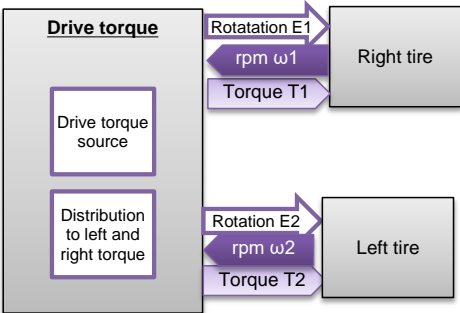
#### 4. Example of subsystem definition document (vehicle dynamic performance)

##### (1) Steering system Model (dynamic performance)

Subsystem I/F Definition		Subsystem Name= Steering (dynamic performance)		
Model function abstract				
		○Function abstract Handle. Torque assist. (motor) Spring, damper. Torque distribution.		
Input				
Plant model I/F				
Name	Unit	Polar direction	Description	
rpm ω1	rad/s	—	rpm from steering system to vehicle	
Torque T2	Nm	Input side = positive	Torque from steering to right front tire	
Torque T3	Nm	Input side = positive	Torque from steering to left front tire	
Controller model I/F				
Name	Unit	Area	Description	
Output				
Plant model I/F				
Name	Unit	Polar direction	Description	
TorqueT1	Nm	Output side = positive	Reaction torque from steering system to vehicle model	
rpm ω2	rad/s	—	rpm of slip angle from right front tire to steering	
rpm ω3	rad/s	—	rpm of slip angle from left front tire to steering	
Controller model I/F				
Name	Unit	Area	Description	
Energy direction				
Name	Energy positive direction		Description	
Rotation E1	Output		Rotational energy from steering system to the vehicle	
Rotation E2	Output		Rotational energy from steering to right front tire	
Rotation E3	Output		Rotational energy from steering to left front tire	
Note				
ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 8th, 2019

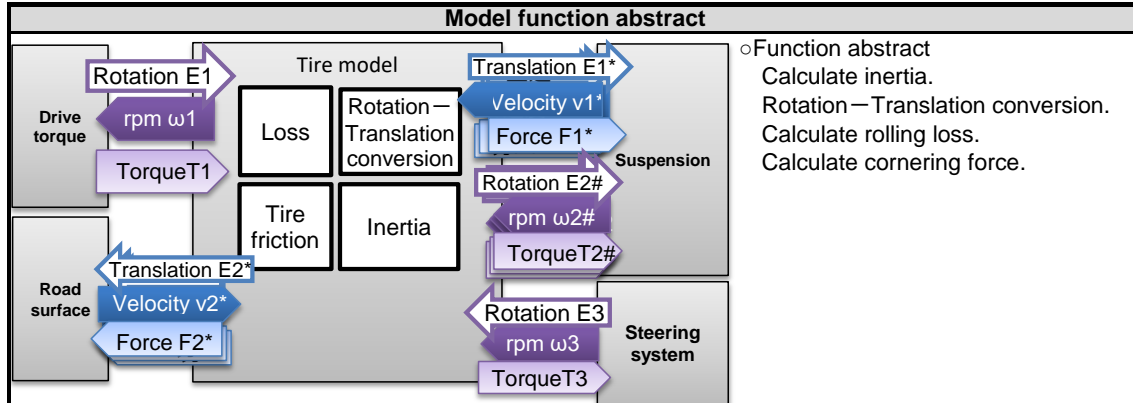


## (2) Drive torque Model (dynamic performance)

Subsystem I/F Definition		Subsystem Name= Drive torque (dynamic performance)	
Model function abstract			
		<div>○Function abstract Transmit torque from differential gear (D/F) model to tires.</div> <div>①Torque source ②Torque distribution</div>	
Input			
Plant model I/F			
Name	Unit	Polar direction	Description
rpm $\omega_1$	rad/sec	—	Right tire rpm
rpm $\omega_2$	rad/sec	—	Left tire rpm
Controller model I/F			
Name	Unit	Area	Description
Output			
Plant model I/F			
Name	Unit	Polar direction	Description
torqueT1	Nm	Output side = positive	Drive torque to right tire
torqueT2	Nm	Output side = positive	Drive torque to left tire
Controller model I/F			
Name	Unit	Area	Description
Energy direction			
Name	Energy positive direction		Description
motion E1	Output		Energy from drive torque to right tire
motion E2	Output		Energy from drive torque to left tire
Note			

### (3) Tire Model (dynamic performance)

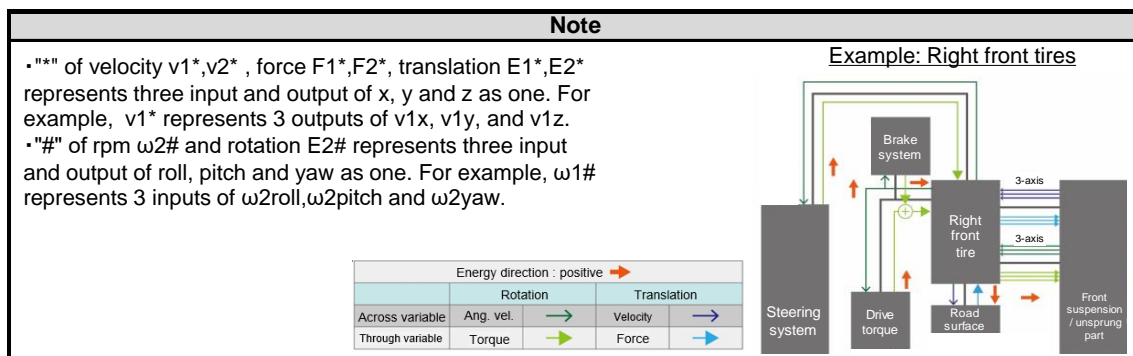
<b>Subsystem I/F Definition</b>	<b>Subsystem Name= Tire (dynamic performance)</b>	
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Input			
Name	Unit	Polar direction	Description
torque T1	Nm	Input side = positive	Input torque from drive torque
Velocity v1*	m/s	—	Unsprung xyz velocity between tire and suspension
rpm ω2#	rad/sec	—	Unsprung roll pitch yaw angular velocity between tire and suspension
Velocity v2*	m/s	—	Tire x,y,z velocity
rpm ω3	rad/s	—	Slip angle rpm from steering to tire
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
rpm ω1	rad/s	—	Tire rpm
Force F1*	N	Output side = positive	3-axis (x,y,z) force to suspension
Torque T2#	Nm	Output side = positive	3-axis torque of roll pitch yaw to suspension
Force F2*	N	Output side = positive	x,y,z axial resistance force of tire
Torque T3	Nm	Output side = positive	Input torque of slip angle from steering system
Name	Unit	Area	Description

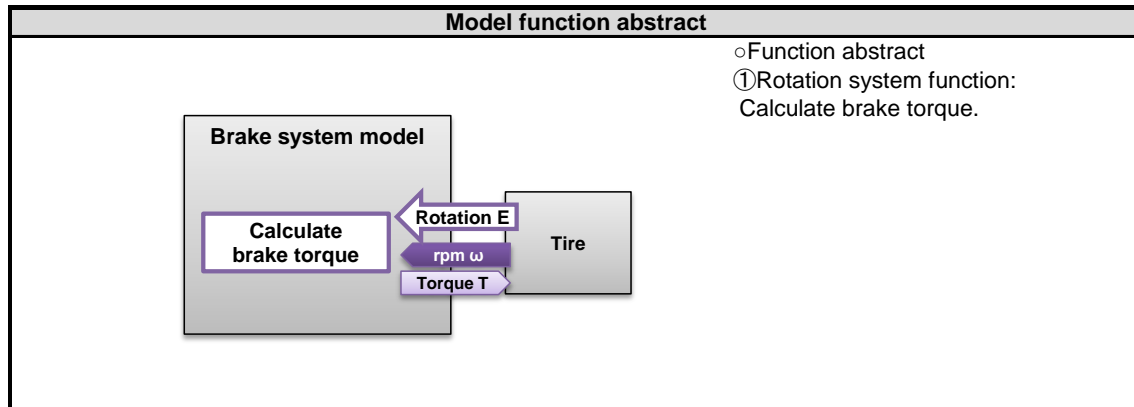
Energy direction		
Name	Energy positive direction	Description
Rotation E1	Input	Input rotational energy from drive torque
Translation E1*	Output	x,y,z- output energy of translation to suspension
Rotation E2#	Output	Output energy of rotation roll pitch yaw to suspension
Translation E2*	Output	Energy to road surface
Rotation E3	Input	Input rotational energy from steering system



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01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2019

#### (4) Brake system Model (dynamic performance)

<b>Subsystem I/F Definition</b>	Subsystem Name= Brake system (dynamic performance)	
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Input			
Name	Unit	Polar direction	Description
rpm $\omega$	rad/s	—	Tire rpm
Name	Unit	Area	Description

Output			
Name	Unit	Polar direction	Description
Torque T	Nm	Output side = positive	Torque at T/M side
Name	Unit	Area	Description

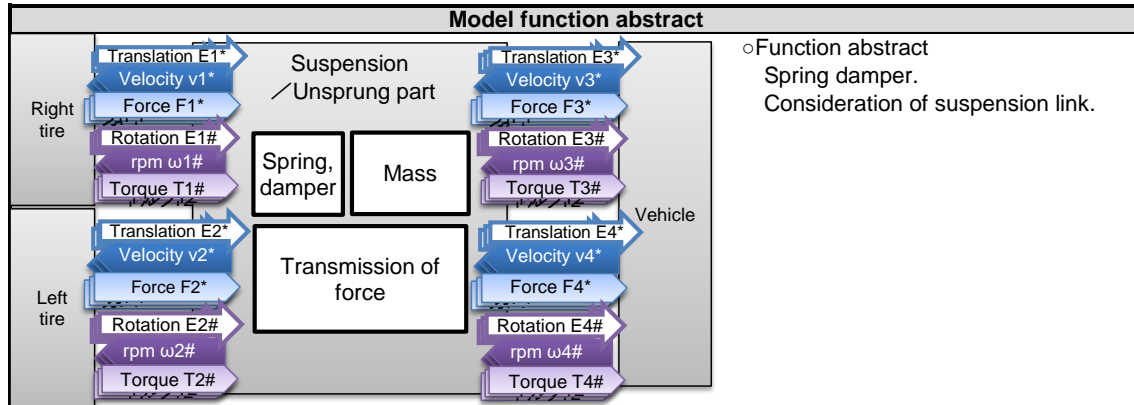
Energy direction		
Name	Energy positive direction	Description
Rotation E	Input to model	Energy of brake system

Note

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01	Initial version	AZAPA	Junichi Ichihara	Mar 8th, 2019

## (5) Suspension/ Unsprung Model (dynamic performance)

<b>Subsystem I/F Definition</b>	Subsystem Name= Suspension /Unsprung part (dynamic performance)
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Input			
Name	Unit	Polar direction	Description
Force F1*,F2*	N	Input side = positive	3-axis (x,y,z) force from tire to suspension
Torque T1#,T2#	Nm	Input side = positive	3-axis torque (roll pitch yaw) from tire to suspension
Velocity v3*,v4*	m/s	—	Vehicle velocity to x, y, z direction
rpm ω3#,ω4#	rad/sec	—	Vehicle velocity to roll pitch yaw direction
Name	Unit	Area	Description
Output			
Name	Unit	Polar direction	Description
Velocity v1*,v2*	m/s	—	Unsprung xyz velocity between tire and suspension
rpm ω1#,ω2#	rad/sec	—	Unsprung roll pitch yaw angular velocity between tire and suspension
Force F3*,F4*	N	Output side = positive	3-axis (x,y,z) force from suspension to vehicle
Torque T3#,T4#	Nm	Output side = positive	3-axis torque of roll pitch yaw from suspension to vehicle
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Translation E1*,E2*	Input	Translational energy from tire to suspension
Rotation E1#,E2#	Input	Rotational energy from tire to suspension
Translation E3*,E4*	Output	Translational energy from suspension to vehicle
Rotation E3#,E4#	Output	Rotational energy from suspension to vehicle

## Note

- "\*" of velocity  $v1^*-v4^*$ , force  $F1^*-F4^*$ , translation  $E1^*-E4^*$  represents three input and output of x, y and z as one. For example,  $v1^*$  represents 3 outputs of  $v1x$ ,  $v1y$ , and  $v1z$ .
- "#" of rpm  $\omega1\#-\omega4\#$ , torque  $T1\#-T4\#$  and rotation  $E1\#-E4\#$  represents three input and output of roll, pitch and yaw as one. For example,  $\omega1\#$  represents 3 inputs of  $\omega2roll$ ,  $\omega2pitch$  and  $\omega2yaw$ .

Energy direction : positive →				
	Rotation		Translation	
Across variable	Ang. vel.	→	Velocity	→
Through variable	Torque	→	Force	→

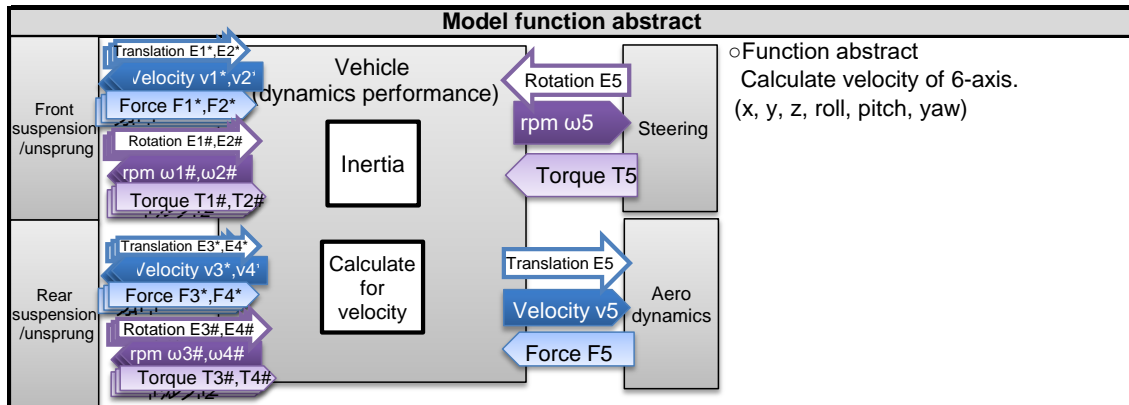
## Example:Front suspension

The diagram illustrates the energy flow in a front suspension system. It shows three main components: the Right front tire, the Left front tire, and the Vehicle (sprung part / gyro / planar motion). The Front suspension / unsprung part is the central component connecting the tires to the vehicle. Energy flows from the tires through the suspension to the vehicle. The diagram uses color-coded arrows to represent different types of energy: blue for rotation and green for translation. Each tire and the vehicle have three inputs/outputs for each type of energy, as indicated by the '3-axis' labels. The suspension part has two inputs/outputs for each type of energy. The energy flow is indicated by red arrows pointing from the tires to the suspension and then to the vehicle.

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## (6) Vehicle Model (dynamic performance)

<b>Subsystem I/F Definition</b>	<b>Subsystem Name= Vehicle (dynamic performance)</b>
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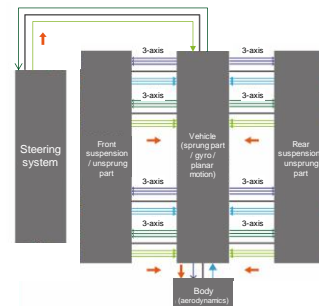
Input			
Name	Unit	Polar direction	Description
Force F1*,F2*	N	Input side = positive	3-axis (x,y,z) force from front suspension to vehicle
Torque T1#,T2#	Nm	Input side = positive	3-axis torque of roll pitch yaw from front suspension to vehicle
Force F3*,F4*	N	Input side = positive	3-axis (x,y,z) force from rear suspension to vehicle
Torque T3#,T4#	Nm	Input side = positive	3-axis torque of roll pitch yaw from rear suspension to vehicle
Torque T5	Nm	Input side = positive	Reaction torque from steering to vehicle
Force F5	N	Input side = positive	Air resistance
Name	Unit	Area	Description
Output			
Name	Unit	Polar direction	Description
Velocity v1*,v2*	m/s	—	Vehicle velocity to x, y, z direction at front suspension side
rpm ω1#,ω2#	rad/sec	—	Vehicle velocity to roll pitch yaw direction at front suspension side
Velocity v3*,v4*	m/s	—	Vehicle velocity to x, y, z direction at rear suspension side
rpm ω3#,ω4#	rad/sec	—	Vehicle velocity to roll pitch yaw direction at rear suspension side
rpm ω5	rad/sec	—	Rotational velocity from steering at vehicle
Velocity v5	m/s	—	Vehicle velocity
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Translation E1*,E2*	Input	Translational energy from left and right front suspension to vehicle
Rotation E1#,E2#	Input	Rotational energy from left and right front suspension to vehicle
Translation E3*,E4*	Input	Translational energy from left and right rear suspension to vehicle
Rotation E3#,E4#	Input	Rotational energy from left and right rear suspension to vehicle
Rotation E5	Input	Rotational energy from steering to vehicle
Translation E5	Output	Translational energy to aerodynamics

## Note

- "\*" of velocity  $v1^*, v2^*$ , force  $F1^*, F2^*$ , translation  $E1^*, E2^*$  represents three input and output of x, y and z as one. For example,  $v1^*$  represents 3 outputs of  $v1x$ ,  $v1y$ , and  $v1z$ .
- "#" of rpm  $\omega2\#$  and rotation  $E2\#$  represents three input and output of roll, pitch and yaw as one. For example,  $\omega1\#$  represents 3 inputs of  $\omega2roll$ ,  $\omega2pitch$  and  $\omega2yaw$ .

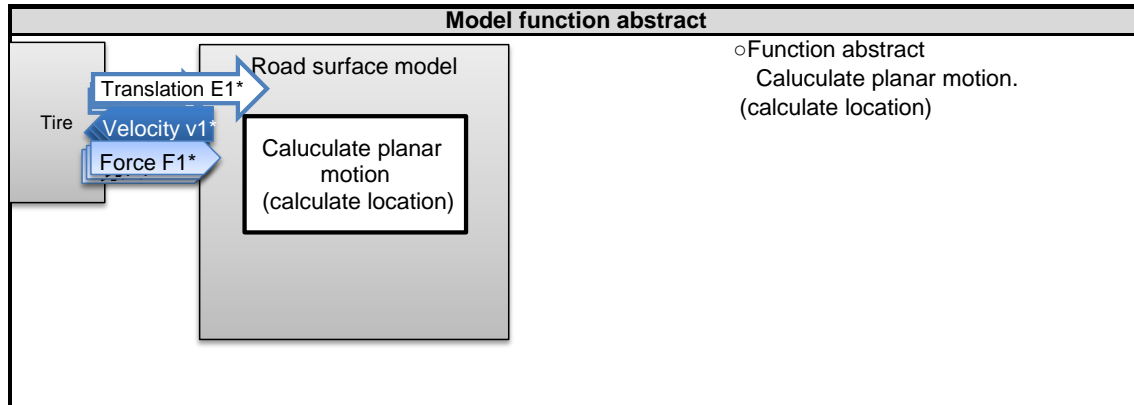
Energy direction : positive →				
	Rotation		Translation	
Across variable	Ang. vel.	→	Velocity	→
Through variable	Torque	→	Force	→



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## (7) Road surface Model (dynamic performance)

<b>Subsystem I/F Definition</b>	Subsystem Name= Road surface (dynamic performance)	
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Input			
Name	Unit	Polar direction	Description
Force F1*	N	Input side = positive	Tire x,y,z axis resistance force
Name	Unit	Area	Description
Output			
Name	Unit	Polar direction	Description
Velocity v1*	m/s	—	Tire x,y,z velocity
Name	Unit	Area	Description

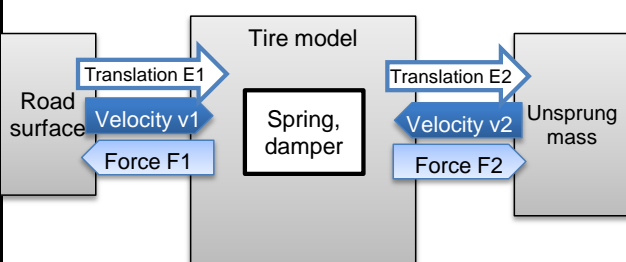
Energy direction		
Name	Energy positive direction	Description
Translation E1*	Input	Energy to road surface

Note
<p>• "*" of velocity v1*, force F1*, translation E1* represents three input and output of x, y and z as one. For example, v1* represents 3 outputs of v1x, v1y, and v1z.</p>

ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2019

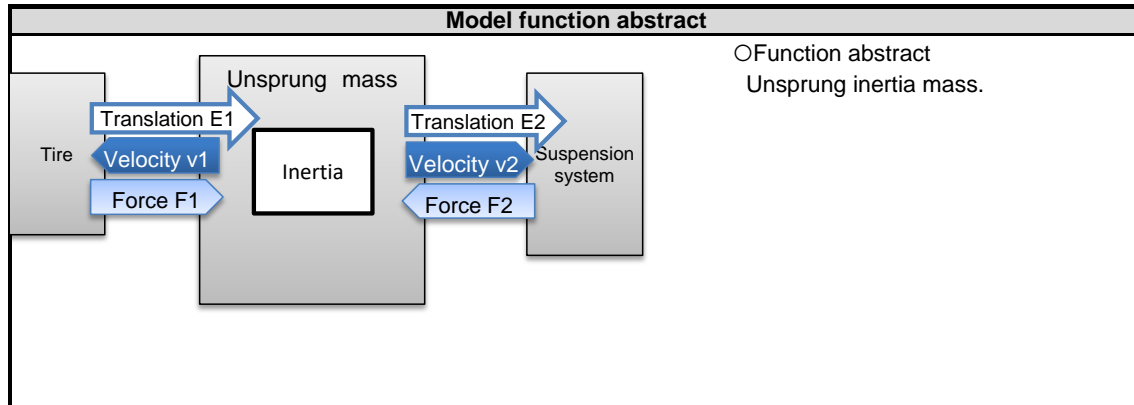
## 5. Example of subsystem definition document (NVH)

### (1) Tire Model (NVH)

Subsystem I/F Definition		Subsystem Name= Tire (NVH)	
Model function abstract			
		○Function abstract Transmission of vertical vibration between road surface and unsprung part.	
Input			
Name	Unit	Polar direction	Description
Velocity v1	m/s	—	Vertical change rate of road surface
Velocity v2	m/s	—	Velocity between unsprung part and tire
Name	Unit	Area	Description
Output			
Name	Unit	Polar direction	Description
Force F1	N	Output side = positive	Force from tire to road surface
Force F2	N	Output side = positive	Force between unsprung part and tire
Name	Unit	Area	Description
Energy direction			
Name	Energy positive direction		Description
Translation E1	Input		Translational energy from road surface to tire
Translation E2	Output		Translational energy from tire to unsprung part
Note			
*Assuming riding comfort at steady speed. Same I/F for front and rear side.			

## (2) Unsprung Model (NVH)

<b>Subsystem I/F Definition</b>	<b>Subsystem Name= Unsprung part (NVH)</b>	
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Input			
Name	Unit	Polar direction	Description
Force F1	N	Input side = positive	Force between suspension system and unsprung part
Force F2	N	Input side = positive	Force between unsprung part and tire
Name	Unit	Area	Description
Output			
Name	Unit	Polar direction	Description
Velocity v1	m/s	—	Velocity between unsprung part and suspension system
Velocity v2	m/s	—	Velocity between unsprung part and tire
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Translation E1	Input	Translational energy from tire to unsprung part
Translation E2	Output	Translational energy from unsprung part to suspension system

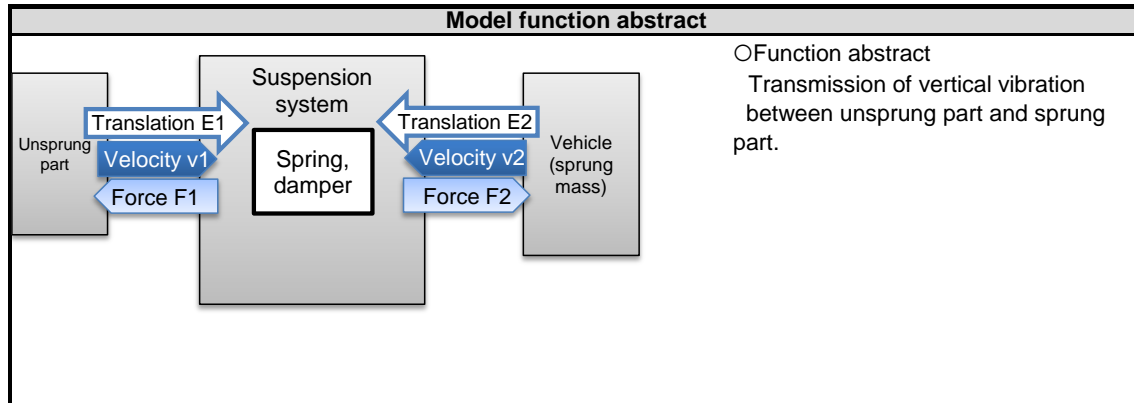
Note
*Assuming riding comfort at steady speed. Same I/F for front and rear side.

ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2019
02	Move the comment from Function abstract to Note	AZAPA	Junichi Ichihara	Mar 16th, 2020



### (3) Suspension system Model (NVH)

<b>Subsystem I/F Definition</b>	<b>Subsystem Name= Suspension system (NVH)</b>	
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Input			
Name	Unit	Polar direction	Description
Velocity v1	m/s	—	Vertical velocity of unsprung part
Velocity v2	m/s	—	Velocity between suspension system and sprung part
Name	Unit	Area	Description
Output			
Name	Unit	Polar direction	Description
Force F1	N	Output side = positive	Force between unsprung part and suspension system
Force F2	N	Output side = positive	Force between suspension system and tire
Name	Unit	Area	Description

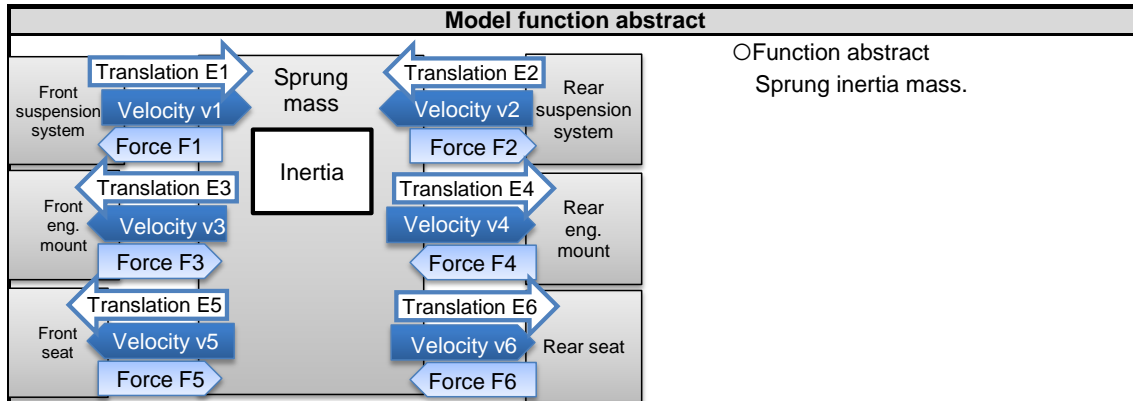
Energy direction		
Name	Energy positive direction	Description
Translation E1	Input	Translational energy from unsprung part to suspension system
Translation E2	Output	Translational energy from suspension system to sprung part

Note
*Assuming riding comfort at steady speed. Same I/F for front and rear side.

ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2019
02	Move the comment from Function abstract to Note	AZAPA	Junichi Ichihara	Mar 16th, 2020

#### (4)Vehicle (Sprung mass) Model (NVH)

<b>Subsystem I/F Definition</b>	<b>Subsystem Name= Vehicle (Sprung mass) (NVH)</b>	
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Input			
Name	Unit	Polar direction	Description
Force F1	N	Input side = positive	Force between front suspension system and sprung part
Force F2	N	Input side = positive	Force between rear suspension system and sprung part
Force F3	N	Input side = positive	Force between front eng.mount and sprung part
Force F4	N	Input side = positive	Force between rear eng.mount and sprung part
Force F5	N	Input side = positive	Force between front seat and sprung part
Force F6	N	Input side = positive	Force between rear seat and sprung part
Name	Unit	Area	Description
Output			
Name	Unit	Polar direction	Description
Velocity v1	m/s	—	Velocity between front suspension system and sprung part
Velocity v2	m/s	—	Velocity between rear suspension system and sprung part
Velocity v3	m/s	—	Velocity between front eng.mount and sprung part
Velocity v4	m/s	—	Velocity between rear eng.mount and sprung part
Velocity v5	m/s	—	Velocity between front seat and sprung part
Velocity v6	m/s	—	Velocity between rear seat and sprung part
Name	Unit	Area	Description

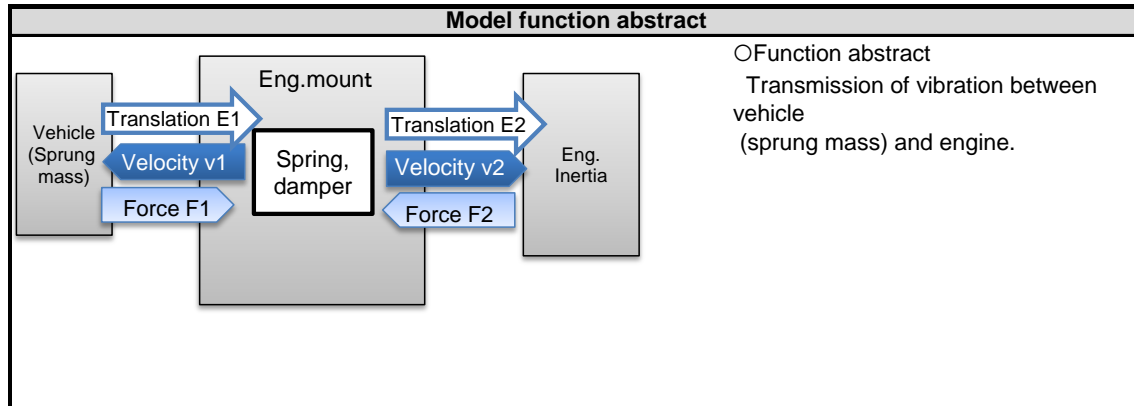
Energy direction		
Name	Energy positive direction	Description
Translation E1	Input	Energy between front suspension system and unsprung part
Translation E2	Input	Energy between rear suspension system and unsprung part
Translation E3	Output	Energy between front eng.mount and sprung part
Translation E4	Output	Energy between rear eng.mount and sprung part
Translation E5	Output	Energy between front seat and sprung part
Translation E6	Output	Energy between rear seat and sprung part

Note
*Assuming riding comfort at steady speed.

ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2019
02	Move the comment from Function abstract to Note	AZAPA	Junichi Ichihara	Mar 16th, 2020
03	Revised error (unsprung⇒sprung)	AZAPA	Junichi Ichihara	Mar 16th, 2020

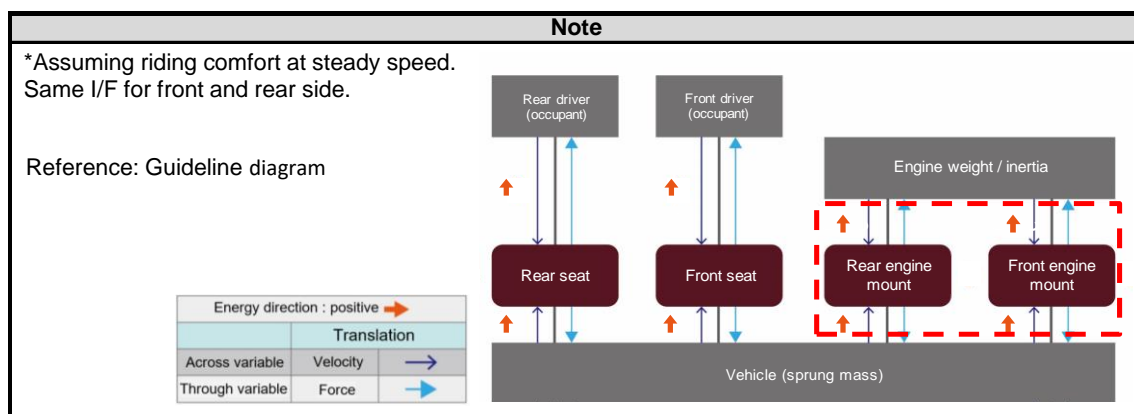
## (5) Engine mount Model (NVH)

<b>Subsystem I/F Definition</b>	<b>Subsystem Name= Eng. mount (NVH)</b>	
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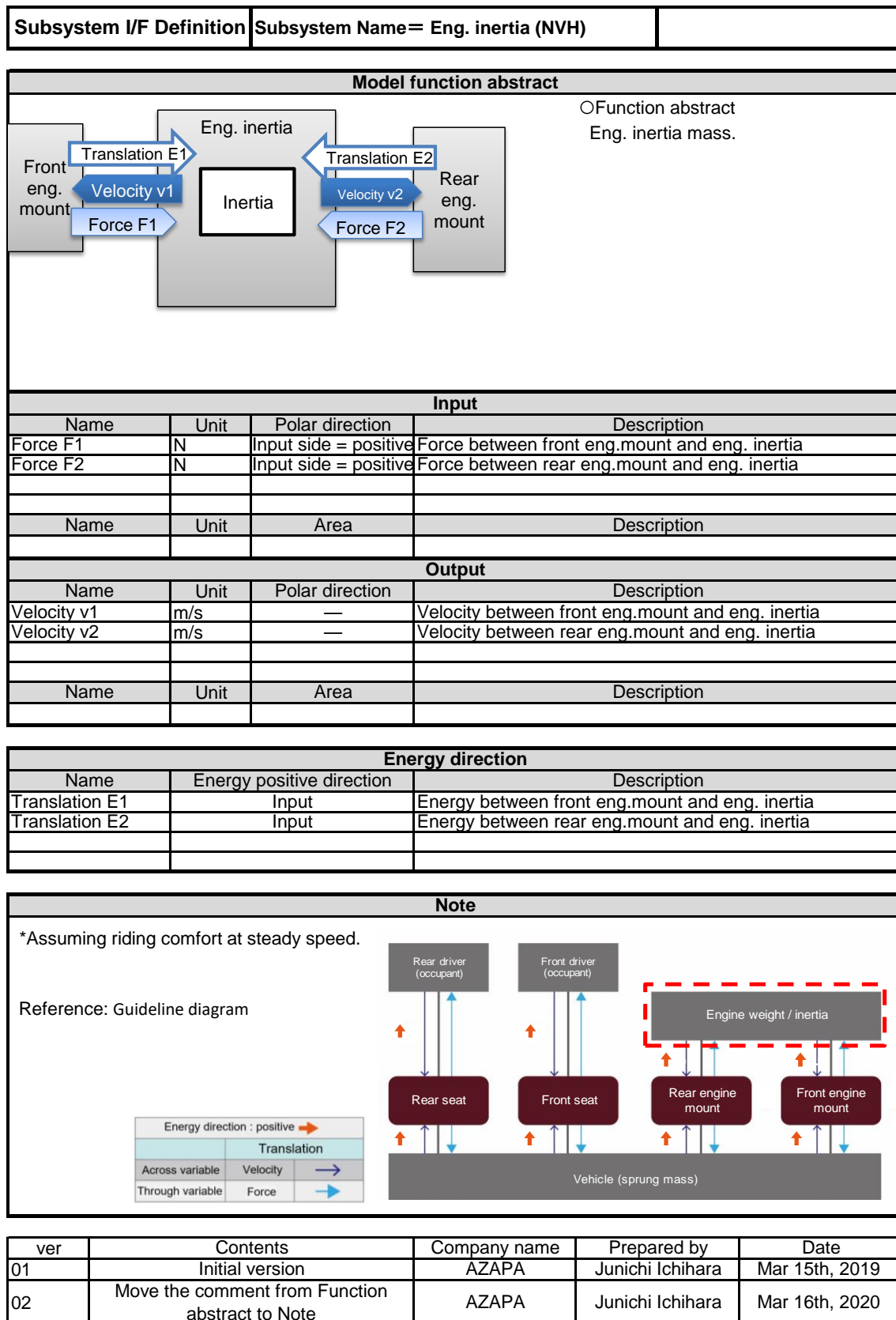
Input			
Name	Unit	Polar direction	Description
Velocity v1	m/s	—	Vertical velocity between vehicle sprung mass and eng.mount
Velocity v2	m/s	—	Vertical velocity between eng.mount and eng.
Name	Unit	Area	Description
Output			
Name	Unit	Polar direction	Description
Force F1	N	Output side = positive	Force between vehicle sprung mass and eng.mount
Force F2	N	Output side = positive	Force between eng.mount and eng.
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Translation E1	Input	Energy between vehicle sprung mass and eng.mount
Translation E2	Output	Energy between eng.mount and eng.



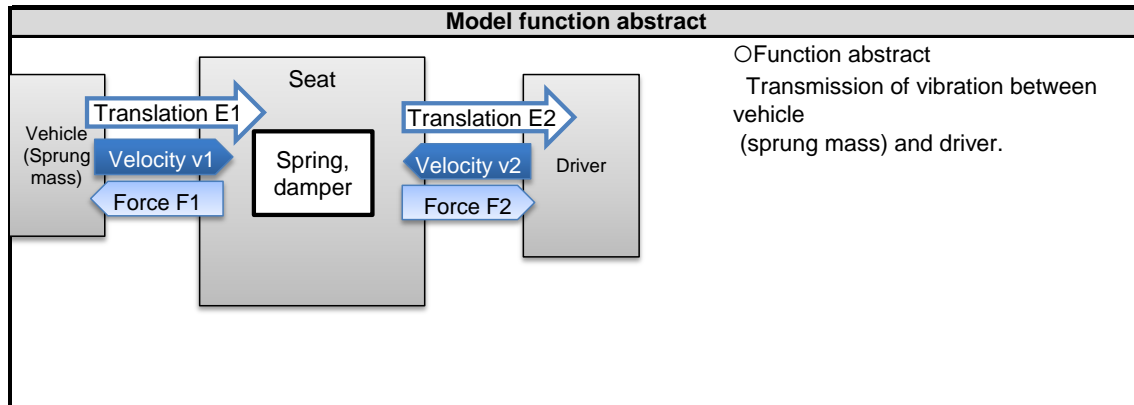
ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2019
02	Move the comment from Function abstract to Note	AZAPA	Junichi Ichihara	Mar 16th, 2020

## (6) Engine inertia Model (NVH)



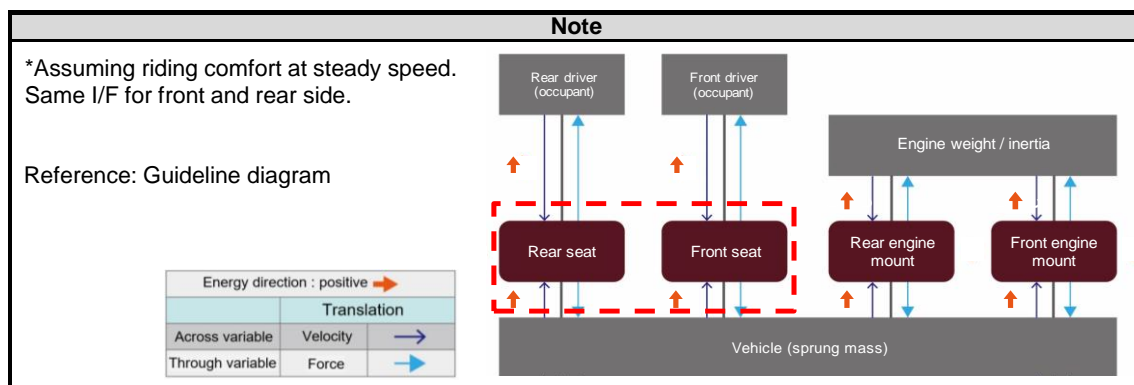
## (7) Seat Model (NVH)

<b>Subsystem I/F Definition</b>	<b>Subsystem Name= Seat (NVH)</b>	
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Input			
Name	Unit	Polar direction	Description
Velocity v1	m/s	—	Vertical velocity between vehicle sprung mass and seat
Velocity v2	m/s	—	Vertical velocity between seat and driver
Name	Unit	Area	Description
Output			
Name	Unit	Polar direction	Description
Force F1	N	Output side = positive	Force between vehicle sprung mass and seat
Force F2	N	Output side = positive	Force between seat and driver
Name	Unit	Area	Description

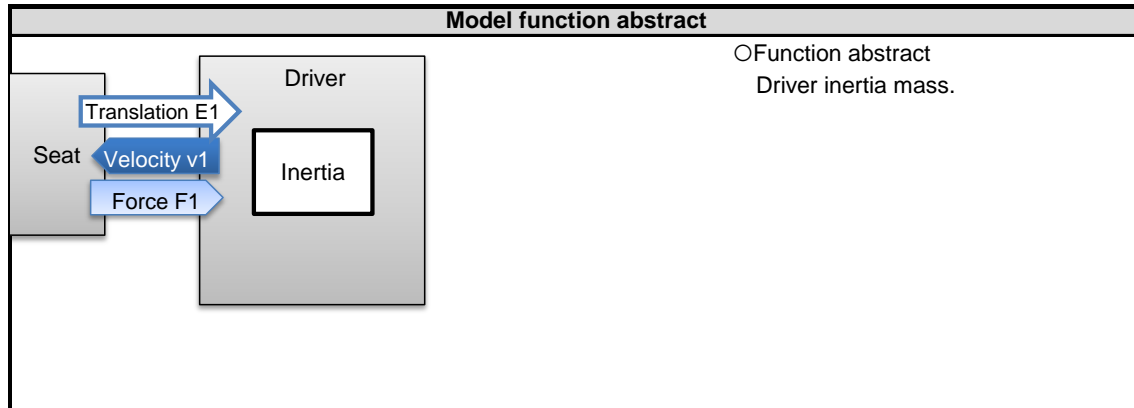
Energy direction		
Name	Energy positive direction	Description
Translation E1	Input	Energy between vehicle sprung mass and seat
Translation E2	Output	Energy between seat and driver



ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2019
02	Move the comment from Function abstract to Note	AZAPA	Junichi Ichihara	Mar 16th, 2020

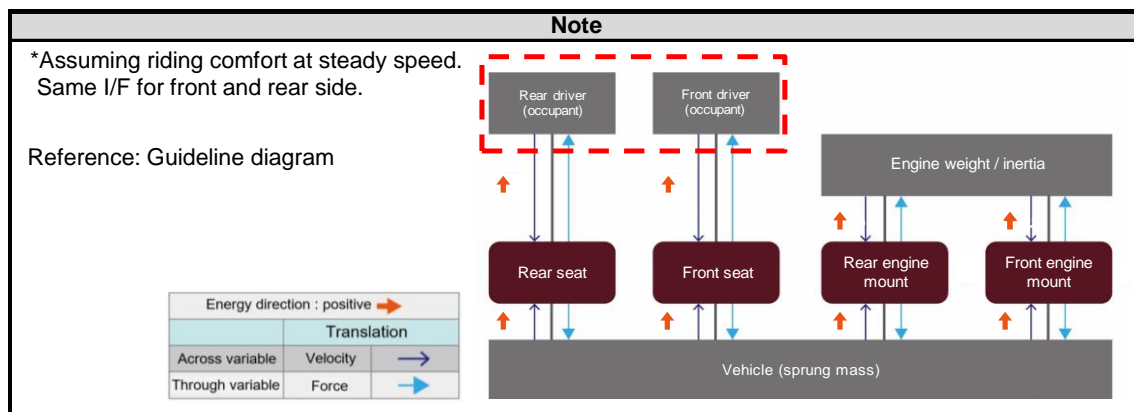
## (8) Driver Model (NVH)

<b>Subsystem I/F Definition</b>	<b>Subsystem Name= Driver (NVH)</b>	
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Input			
Name	Unit	Polar direction	Description
Force F1	N	Input side = positive	Force between seat and driver
Name	Unit	Area	Description
Output			
Name	Unit	Polar direction	Description
Velocity v1	m/s	—	Velocity between seat and driver
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Translation E1	Input	Energy between seat and driver



ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2019
02	Move the comment from Function abstract to Note	AZAPA	Junichi Ichihara	Mar 16th, 2020

(9) Road surface Model (NVH)

<b>Subsystem I/F Definition</b>	<b>Subsystem Name= Road surface (NVH)</b>	
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Model function abstract	
	<p>○Function abstract Transmission of vertical vibration of road surface to tire.</p> <p>Assuming riding comfort at steady speed. Same I/F for front and rear side.</p>

Input			
Name	Unit	Polar direction	Description
Force F1	N	Input side = positive	Force from tire to road surface
Name	Unit	Area	Description
Output			
Name	Unit	Polar direction	Description
Velocity v1	m/s	—	Vertical change rate of road surface
Name	Unit	Area	Description

Energy direction		
Name	Energy positive direction	Description
Translation E1	Output	Translational energy from road surface to tire

Note
<p>*Assuming riding comfort at steady speed. Same I/F for front and rear side.</p>

ver	Contents	Company name	Prepared by	Date
01	Initial version	AZAPA	Junichi Ichihara	Mar 15th, 2019
02	Move the comment from Function abstract to Note	AZAPA	Junichi Ichihara	Mar 16th, 2020

## <Reference document>

Document 1    Guideline for FMI Model Connection using Noncausal Modeling Tool  
Ver.1.0    <https://www.jsae.or.jp/tops/topics/1241/1241-1A.pdf>  
March, 2015

Joint Research Center, Society of Automotive Engineers of Japan, Inc.  
Committee of Model Development and Distribution by International  
Standard Description  
Model Connection Technique WG

Ver.	Revised content	Date
01	New issued.	Mar 15 <sup>th</sup> , 2017
02	Added guidelines of P/T thermal system. Added guidelines for example of vehicle dynamic performance. Added guidelines for example of NVH. Changed term from subsystem to system.	Mar 15 <sup>th</sup> , 2019
02-01	Temporary delete of guidelines for example of vehicle dynamic performance because of updating contents. Temporary delete of guidelines for example of NVH because of updating contents.	Nov 13 <sup>th</sup> , 2019
03	Revised error Added incompressible fluid and compressible fluid as preliminary version. Added guidelines for electric consumption for electric vehicles.	Nov 13 <sup>th</sup> , 2019 Mar 23 <sup>th</sup> , 2020 Mar 18 <sup>th</sup> , 2020
04	Added guideline about coordinate system of dynamic performance. Described the use case for incompressible fluid and compressible fluid of first and third principles.	Mar 15 <sup>th</sup> , 2021
04-01	error correction( P5,P18 fig19)	Sep 1 <sup>st</sup> , 2021