Autonomous Vehicle Simulation (AVS) Laboratory, University of Colorado

Basilisk Technical Memorandum

Document ID: Basilisk-reactionWheelStateEffector

REACTION WHEEL DYNAMICS MODEL

Prepared by	C. Allard

Status: To Be Reviewed
Scope/Contents
The reaction wheel class is an instantiation of the state effector abstract class. The integrated test is validating the interaction between the reaction wheel module and the rigid body hub that it is attached to. More specifically, the reaction wheel module models three different cases: balanced wheels, simpled jitter, and fully coupled jitter. The details of each mode is described in detail in this document. This integrated test confirms that all three models are agreeing with physics and the tests use both energy and momentum checks and back of the envelope (BOE) calculations.

Rev	Change Description	By	Date
1.0	Initial Draft	C. Allard	20170816

Contents

1 Model Description

1.1 Introduction

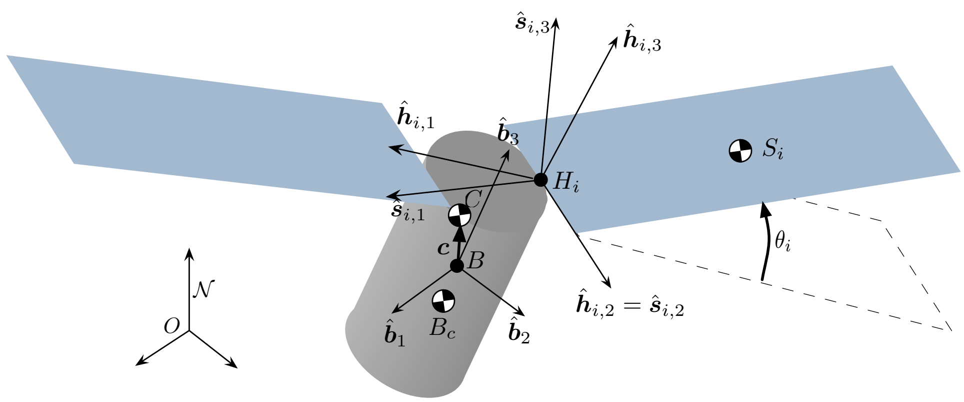

Fig. 1: Hinged rigid body frame and variable definitions

1.2 Equations of Motion

2 Model Functions

This model is used to approximate the behavior of a reaction wheel. Below is a list of functions that this model performs:

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3 Model Assumptions and Limitations

Below is a summary of the assumptions/limitations:

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4 Test Description and Success Criteria

The tests are located in `SimCode/dynamics/reactionWheels/_UnitTest/test_reactionWheelStateEffector_integrated.py` **and** `SimCode/dynamics/reactionWheels/_UnitTest/ test_reactionWheelStateEffector_ConfigureRWRequests.py`. Depending on the test, there are different success criteria. These are outlined in the following subsections:

4.1 Balanced Wheels Scenario - Integrated Test

In this test the simulation is placed into orbit around Earth with point gravity, has 3 reaction wheels attached to the spacecraft, and the wheels are in "Balanced" mode. Each wheel is given a commanded torque for half the simulation and the rest of the simulation the torques are set to zero. The following parameters are being tested:

- Conservation of orbital angular momentum
- Conservation of orbital energy
- Conservation of rotational angular momentum
- Conservation of rotational energy (second half of the simulation)
- Achieving the expected final attitude
- Achieving the expected final position

4.2 Simple Jitter Scenario - Integrated Test

In this test the simulation is placed into orbit around Earth with point gravity, has 3 reaction wheels attached to the spacecraft, and the wheels are in "Simple Jitter" mode. Each wheel is given a commanded torque for half the simulation and the rest of the simulation the torques are set to zero. The following parameters are being tested:

- Achieving the expected final attitude
- Achieving the expected final position

4.3 Fully Coupled Jitter Scenario - Integrated Test

In this test the simulation is placed into orbit around Earth with point gravity, has 3 reaction wheels attached to the spacecraft, and the wheels are in "Fully Coupled Jitter" mode. Each wheel is given a commanded torque for half the simulation and the rest of the simulation the torques are set to zero. The following parameters are being tested:

- Conservation of orbital angular momentum
- Conservation of orbital energy
- Conservation of rotational angular momentum
- Conservation of rotational energy (second half of the simulation)
- Achieving the expected final attitude
- Achieving the expected final position

4.4 BOE Calculation Scenario - Integrated Test

For this

4.5 Friction Scenario - Integrated Test

In the test the goal is to validate that the friction model is matching the desired

4.6 Saturation - Unit Test

4.7 Minimum Torque - Unit Test

5 Test Parameters

Since this is an integrated test, the inputs to the test are the physical parameters of the spacecraft along with the initial conditions of the states. These parameters are outlined in Tables 2- 5. Additionally, the error tolerances can be seen in Table 6.

Table 2: Spacecraft Hub Parameters

Name	Description	Value	Units
mHub	mass	750.0	kg
IHubPntBc_B	Inertia in $\mathcal{B}$ frame	$\begin{bmatrix} 900.0 & 0.0 & 0.0 \\ 0.0 & 600.0 & 0.0 \\ 0.0 & 0.0 & 600.0 \end{bmatrix}$	kg-m^2
r_BcB_B	CoM Location in $\mathcal{B}$ frame	$[0.0 \quad 0.0 \quad 1.0]^T$	m

Table 3: Hinged Rigid Body 1 Parameters

Name	Description	Value	Units
mass	mass	100.0	kg
IPntS_S	Inertia in $\mathcal{S}$ frame	$\begin{bmatrix} 100.0 & 0.0 & 0.0 \\ 0.0 & 50.0 & 0.0 \\ 0.0 & 0.0 & 50.0 \end{bmatrix}$	kg-m^2
d	CoM location	1.5	m
k	Spring Constant	100.0	N-m/rad
c	Damping Term	0.0 (6.0 - damping scenario)	N-m-s/rad
r_HB_B	Hinge Location in $\mathcal{B}$ frame	$[0.5 \quad 0.0 \quad 1.0]^T$	m
dcm_HB	$\mathcal{B}$ to $\mathcal{H}$ DCM	$\begin{bmatrix} -1.0 & 0.0 & 0.0 \\ 0.0 & -1.0 & 0.0 \\ 0.0 & 0.0 & 1.0 \end{bmatrix}$	-

Table 4: Hinged Rigid Body 2 Parameters

Name	Description	Value	Units
mass	mass	100.0	kg
IPntS_S	Inertia in $\mathcal{S}$ frame	$\begin{bmatrix} 100.0 & 0.0 & 0.0 \\ 0.0 & 50.0 & 0.0 \\ 0.0 & 0.0 & 50.0 \end{bmatrix}$	kg-m^2
d	CoM location	1.5	m
k	Spring Constant	100.0	N-m/rad
c	Damping Term	0.0 (7.0 - damping scenario)	N-m-s/rad
r_HB_B	Hinge Location in $\mathcal{B}$ frame	$\begin{bmatrix} -0.5 & 0.0 & 1.0 \end{bmatrix}^T$	m
dcm_HB	$\mathcal{B}$ to $\mathcal{H}$ DCM	$\begin{bmatrix} 1.0 & 0.0 & 0.0 \\ 0.0 & 1.0 & 0.0 \\ 0.0 & 0.0 & 1.0 \end{bmatrix}$	-

Table 5: Initial Conditions for Energy Momentum Conservation Scenarios

Name	Description	Value	Units
(Panel 1) thetaInit	(Panel 1) Initial θ	5.0	deg
(Panel 1) thetaDotInit	(Panel 1) Initial $\dot{\theta}$	0.0	deg
(Panel 2) thetaInit	(Panel 2) Initial θ	0.0	deg
(Panel 2) thetaDotInit	(Panel 2) Initial $\dot{\theta}$	0.0	deg
r_CN_NInit	Initial Position of S/C (gravity scenarios)	$\begin{bmatrix} -4020339 & 7490567 & 5248299 \end{bmatrix}^T$	m
v_CN_NInit	Initial Velocity of S/C (gravity scenarios)	$\begin{bmatrix} -5199.78 & -3436.68 & 1041.58 \end{bmatrix}^T$	m/s
r_CN_NInit	Initial Position of S/C (no gravity)	$\begin{bmatrix} 0.1 & -0.4 & 0.3 \end{bmatrix}^T$	m
v_CN_NInit	Initial Velocity of S/C (no gravity)	$\begin{bmatrix} -0.2 & 0.5 & 0.1 \end{bmatrix}^T$	m/s
sigma_BNInit	Initial MRP of $\mathcal{B}$ frame	$\begin{bmatrix} 0.0 & 0.0 & 0.0 \end{bmatrix}^T$	-
omega_BN_BInit	Initial Angular Velocity of $\mathcal{B}$ frame	$\begin{bmatrix} 0.1 & -0.1 & 0.1 \end{bmatrix}^T$	rad/s

Table 6: Error Tolerance - Note: Relative Tolerance is $\text{abs}(\frac{\text{truth}-\text{value}}{\text{truth}})$

Test	Relative Tolerance
Energy and Momentum Conservation	1e-10
Steady State Deflection	1e-6
Frequency verification	5e-3
Max deflection with force on	5e-3
Max deflection with force off	5e-3
Lagrangian vs Basilisk comparison	1e-10

6 Test Results

7 User Guide

This section is to outline the steps needed to setup a reaction wheel state effector in python using Basilisk.

1. Import the reactionWheelStateEffector class:
   import reactionWheelStateEffector

2. Create an instantiation of a reaction wheel state effector:
   rws = reactionWheelStateEffector.ReactionWheelStateEffector()

3. Finally, add the reaction wheel object to your spacecraftPlus:
   scObject.addStateEffector(rws). See spacecraftPlus documentation on how to set up a spacecraftPlus object.

REFERENCES

[1] C. Allard, Hanspeter Schaub, and Scott Piggott. General hinged solar panel dynamics approximating first-order spacecraft flexing. In *AAS Guidance and Control Conference*, Breckenridge, CO, Feb. 5–10 2016. Paper No. AAS-16-156.