USING THE STRAPDOWN INERTIAL SENSOR MODEL

TAPESTRY, with the Multi-Function Input/Output [**MFIO**] feature card installed, will model the Electrical and Data Protocol for **STRAPDOWN** Inertial Measurement Units implemented Digitally via **SDLC / ± RS422** and in Analog via a **16 BIT D2A**.

The digital output characteristics:

- Scaled and Interleaved, Autopilot and Inertial Data [Δv and $\Delta\theta$] at 0 - 1.2 KHz
- SDLC / ± RS422 Transparent Mode, CRC, 0-BIT Insert.
- Source/Slave 1 MHz Data Clock.
- DB25 on MFIO Tang.

The analog output characteristics:

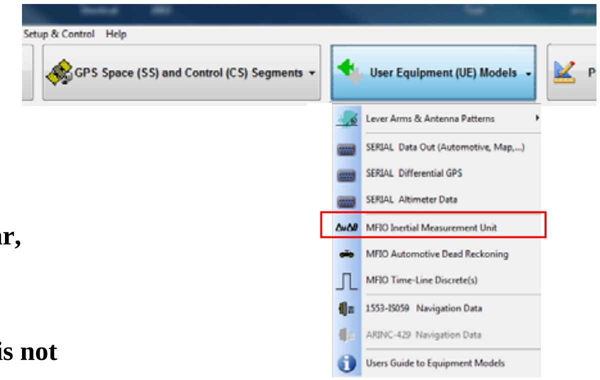
- Rate Gyro Triad, 0-5 VDC, 50Ω. Programmable scale factor and offset.
- Accelerometer Triad, 0-5 VDC, 50Ω. Programmable scale factor and offset.
- 16 bit D2A / 100 Hz update.
- DB25 on MFIO Tang.

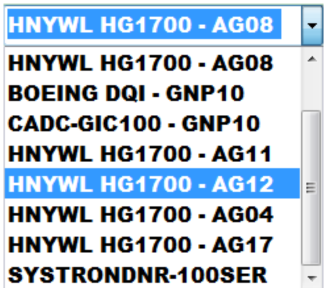
In all configurations,

- Per-axis error models.
- Case-to-body axis modeling.
- Adaptation parameter modeling.
- Truth data access for analysis support.

This document provides a description of the Setup and Modeling associated with our implementation of Inertial Measurement Unit (IMU) data output.

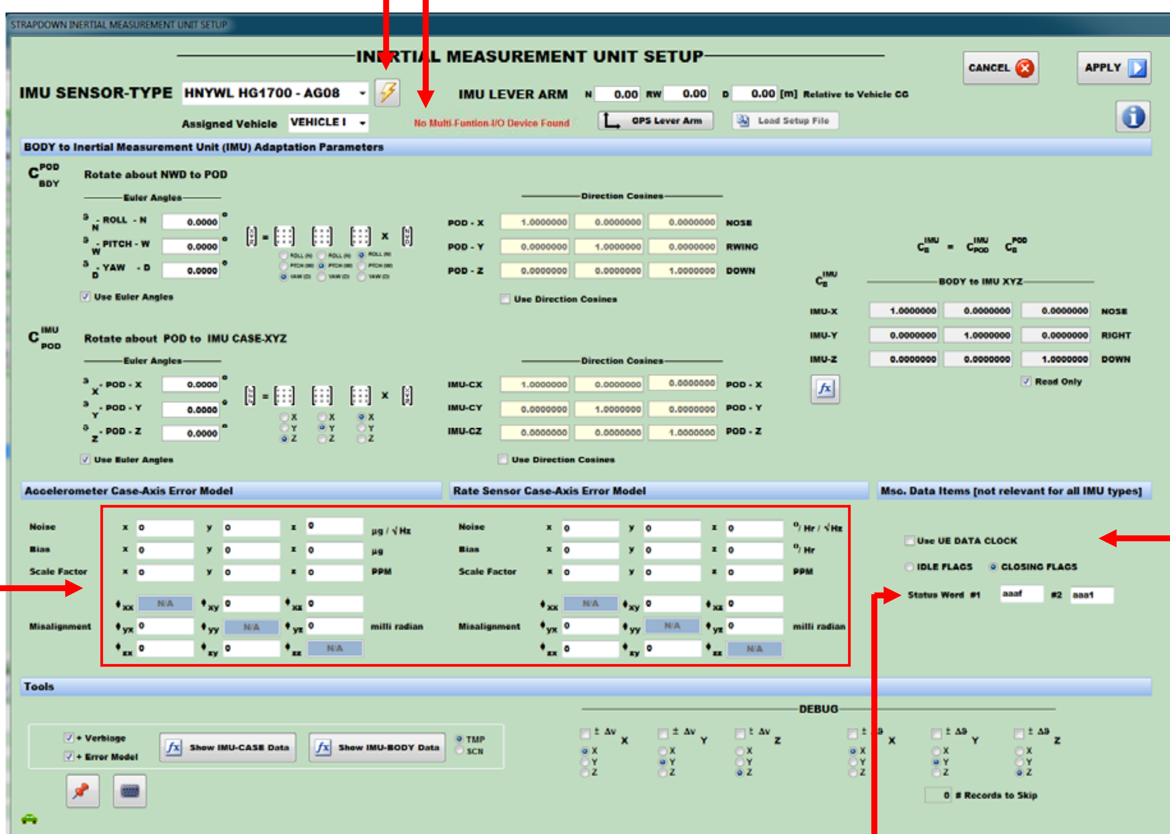
THE INERTIAL MEASUREMENT UNIT MODEL





If this ICON appears, Press to flash the MFIO expansion card. If it does not appear, the IMU is already flashed.

If the MFIO expansion card is not detected, this message will be displayed



Check top use the UE Data Clock, otherwise Tapestry sources the Data Clock.

Enter (if required) Status words in hex (eg. 0xaa). See your IMU interface documentation for the correct settings of these items

Error Model

Note: The IMU models require the Multi-Function I/O [MFIO] for data output.

INERTIAL MEASUREMENT UNIT TYPE

If displayed, click the Flash control to program the MFIO with the correct firmware. If you select a different IMU type repeat the programming procedure.

There are 4 (Generic) Output Data Formats for HG1700 we supply

HNYWL HG1700 - AG04
HNYWL HG1700 - AG08
HNYWL HG1700 - AG11
HNYWL HG1700 - AG17

Enter the applicable implementation from the table into the Control.

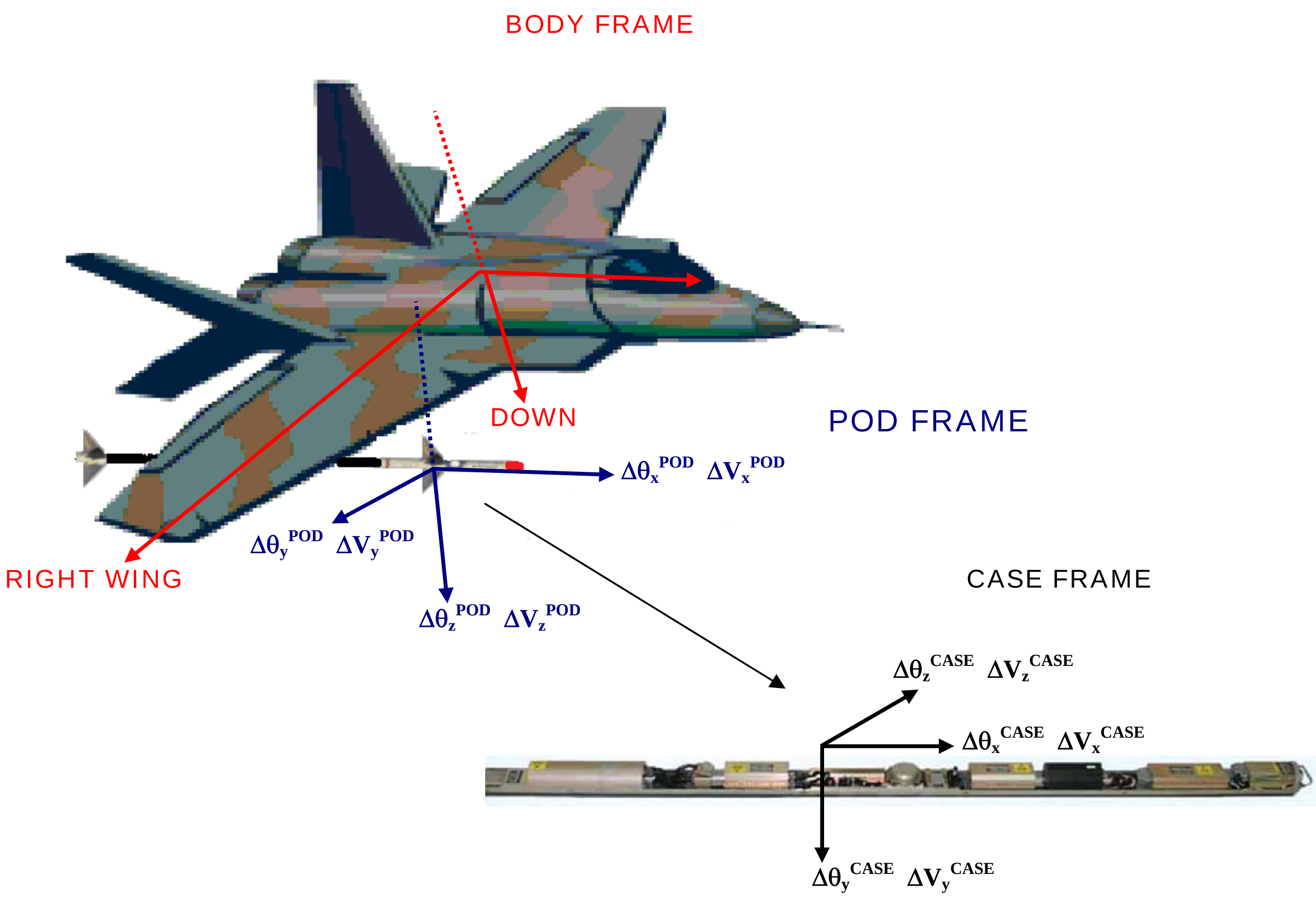
HG1700 IDENTIFICATION TYPE	600 Hz AP	100 Hz NAV	50 Hz NAV	User UE Clock	SDLC	CLOCK ± 2%	ACCEL SCALE FACTOR	GYRO SCALE FACTOR	TAPESTRY SELECTION
HG1700 AG08	X	X				999 KHz	7.99E-04	5.41E-06	AG08
HG1700 AG41/71	X	X				999 KHz	7.99E-04	5.41E-06	AG08
HG1700 AG42/72	X	X				999 KHz	7.99E-04	5.41E-06	AG08
HG1700 AG43/73	X	X				999 KHz	7.99E-04	5.41E-06	AG08
HG1700 AG44	X	X				999 KHz	7.99E-04	5.41E-06	AG08
HG1700 AG14		X		X		999 KHz	6.56E-04	4.00E-06	NI
HG1700 AG40		X		X		999 KHz	6.56E-04	4.00E-06	NI
HG1700 AG51		X		X		999 KHz	6.56E-04	4.00E-06	NI
HG1700 AG31	X	X				999 KHz	7.99E-04	5.41E-06	NI
HG1700 AG05	X	X		X	X	1 MHz	7.45E-09	2.32E-10	NI
HG1700 AG11	X	X		X	X	1 MHz	7.45E-09	1.16E-10	AG11
HG1700 AG12	X	X		X	X	1 MHz	7.45E-09	1.16E-10	AG11
HG1700 AG13	X	X		X	X	1 MHz	7.45E-09	1.16E-10	AG11
HG1700 AG19	X	X		X	X	1 MHz	7.45E-09	1.16E-10	AG11
HG1700 AG22	X	X		X	X	1 MHz	7.45E-09	1.16E-10	AG11
HG1700 AG03		X		X	X	1 MHz	7.45E-09	1.16E-10	AG11
HG1700 AG17	X	X		X	X	1 MHz	1.49E-08	1.16E-10	AG17
HG1700 AG21	X	X		X	X	1 MHz	1.49E-08	1.16E-10	AG17
HG1700 AG04		X		X	X	1 MHz	9.76E-04	1.90E-06	AG04
HG1700 AG24	X	X		X	X	1 MHz	7.45E-09	5.72E-04	NI
HG1700 AG09			X	X	X	1 MHz	7.45E-09	1.16E-10	NI
HG1700 AE03		X		X	X	1 MHz	2.00E-27	2.00E-33	NI
HG1700 AE04		X		X	X	1 MHz	2.00E-10	2.00E-19	NI
HG1700 AE05			X	X	X	1 MHz	2.00E-27	2.00E-33	NI
HG1700 AE09	X	X		X	X	1 MHz	2.00E-27	2.00E-33	NI
HG1700 AE11	X	X		X	X	1 MHz	2.00E-27	2.00E-33	NI
HG1700 AE12	X	X		X	X	1 MHz	2.00E-27	2.00E-33	NI
HG1700 AE13	X	X		X	X	1 MHz	2.00E-27	2.00E-33	NI

Not Implemented

BODY TO SENSOR ALIGNMENT C^{POD}_{BODY} - C^{IMU}_{POD} - C^{IMU}_{BODY}

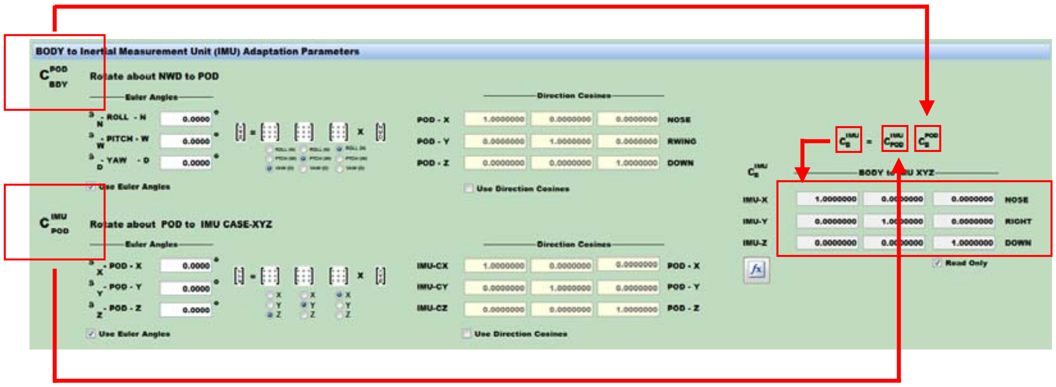
Experience has taught, this topic is crucial to correct performance of the simulator. Tapestry nominally configures the IMU/IRU ***case*** frame **-** the frame in which the Output Inertial Data is referenced **-** in perfect alignment with the vehicle BODY frame. The BODY frame is aligned with the vehicle Nose (Forward), Right Wing, and Down axis. There is a third modeled frame, the Navigation-POD frame. This frame is the mounting frame for the sensor CASE frame. This allows the IMU to be mounted at an offset relative to the carrying POD. By Default the POD is a UNIT matrix thus equating the POD and CASE axis.

The figure illustrates the three coordinate frames and associated notation. The shown alignment of the POD and CASE are illustrative.



This document provides the details of our Matrix definitions and Operations.

If you wish to specify a different alignment, the ***Adaptation Parameters*** controls are provided.



This Matrix transforms Truth Data from BODY to IMU-CASE

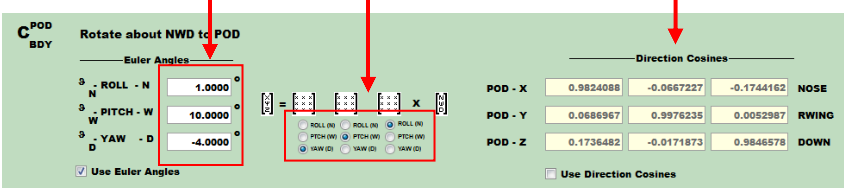
EXAMPLE
Euler Angles, Rotation Order YPR
POD Angles = 0 (NO POD)

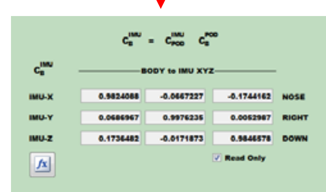
Enter Rotation Angles

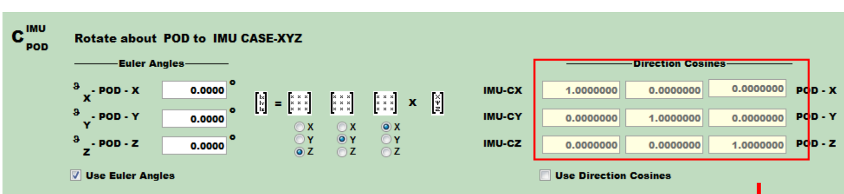
Specify Rotation Order

Resultant Rotation Matrix (computed by Tapestry)

Resultant BODY to CASE Matrix (computed by Tapestry)

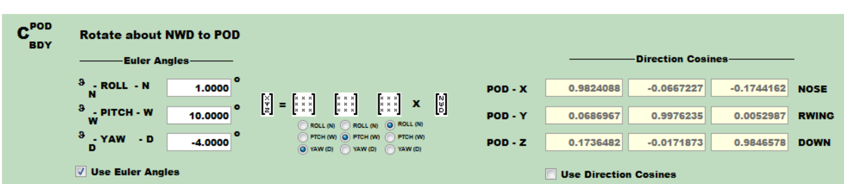


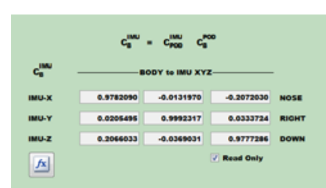


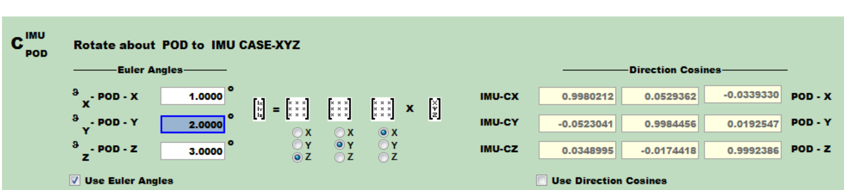


0 Angle = No POD (UNIT Matrix)

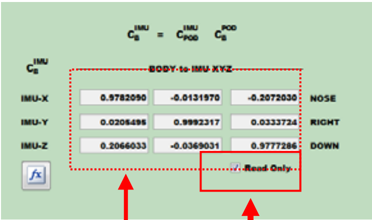
EXAMPLE
Euler Angles, Rotation Order YPR
POD Angles, Rotation Order ZYX

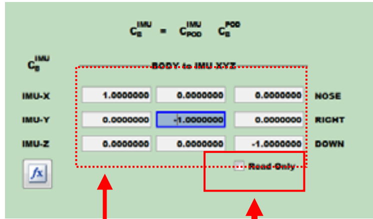






READ ONLY
User defines the BODY to CASE Transformation Explicitly

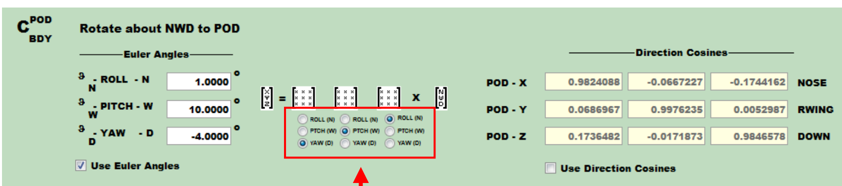




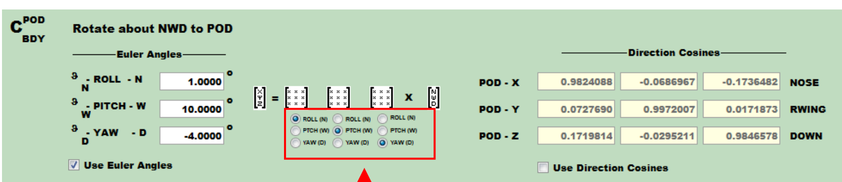
Controls are READ ONLY if Checked
computed from input Euler Angles

UN-CHECKED, User entered values define the Matrix.
Euler Angles are ignored

MATRIX MULTIPLICATION CONVENTIONS
User controls Rotation Matrix Order Conventions

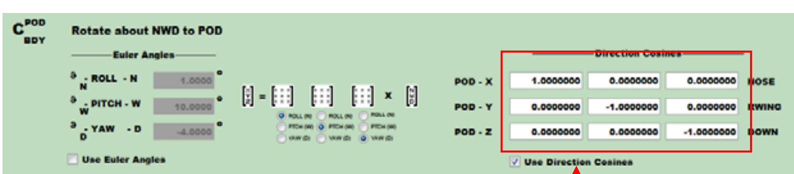


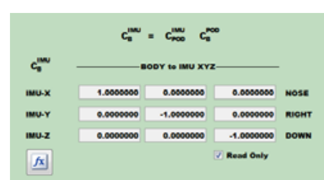
R(YAW) R(PITCH) R(ROLL)



R(ROLL) R(PITCH) R(YAW)

USE DIRECTION COSINES
User specifies Intermediate Direction Cosines Explicitly.

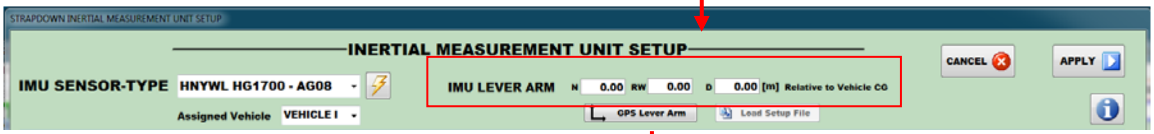


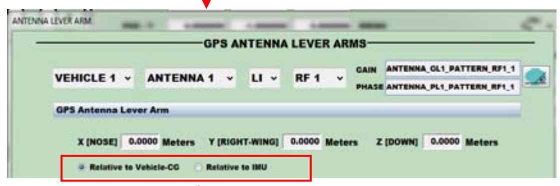


Euler Angles are ignored - Matrix used directly.

Enter offset of IMU sensor relative to Vehicle cg.

IMU LEVER ARM

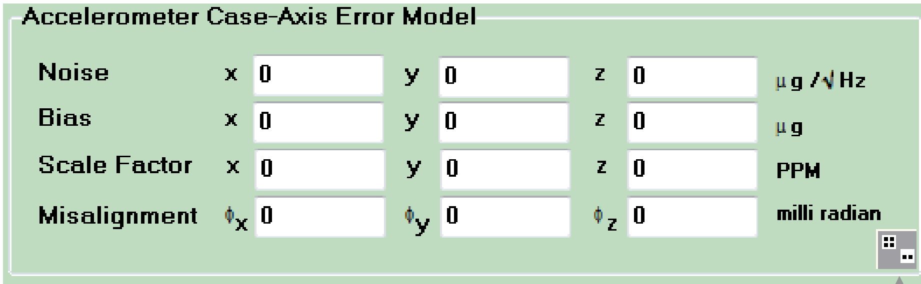




Check this if your GPS Antenna Lever Arm is specified relative to the IMU

ACCELEROMETERS

TAPESTRY models a triad of three accelerometers mounted in the *sensor case* frame **[Δv^C]**. An error model is provided that can be used to support analysis and design.



Each sensitive axis is modeled independently.

Press this button and Tapestry will randomly select the values in the controls by assuming the user-entered values represent a one-sigma

The Error Model is:

$$\Delta\upsilon^C = \Delta\upsilon^T + \beta + (1 + \alpha)\Delta\upsilon^T + \varphi \times \Delta\upsilon^T + \sigma W$$

Where $\Delta\upsilon^T$ is the TRUE delta velocity based upon the Truth Data, $\Delta\upsilon^C$ is the measured Delta Velocity output in the CASE frame via the MFIO. The remaining terms are defined as follows:

Noise (σ W)

σ is the standard deviation of a gaussian white noise process (W) used to apply jitter to the output delta velocity. This error is typically due to sensor measurement electronics. Enter the value for each case axis (x, y, z) in units of micro G (µg). A micro-G is given by

$$1\mu g = 1.0 \times 10^{-6} G \approx 0.00001 \text{ m/s}^2$$

Bias (β)

This value corresponds to the non-zero accelerometer measurement output for a zero applied acceleration input. The units are µg's with 1 µg ≈ 0.00001 m/s^2

Scale Factor (α)

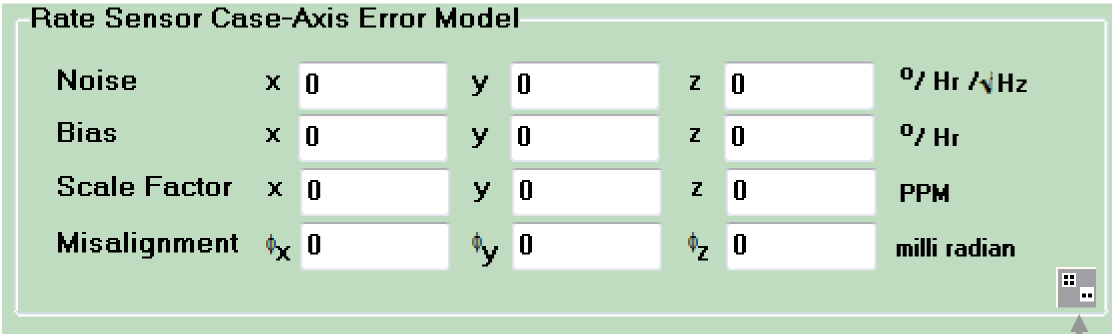
A non-zero scale factor causes the output delta velocity to be in error proportional to the true acceleration, input along the defined axis. The input units are parts-per-million (PPM). 1 PPM = 1.0×10^{-6}

Misalignment (φ)

The accelerometer triad is aligned in an orthogonal triad along the Case Sensitive Axis. This item represents a small error in the alignment. This error causes a sensed acceleration to be projected into one of the cross Case axis. The input units are milli-radian or 0.001 radians. The labels on the data field indicate the axis mixing – for example φ_{XY} rotates **[y]** acceleration into the **[x]** case axis.

RATE SENSORS (GYRO)

TAPESTRY models a triad of three gyroscopic-type angle measuring devices mounted in the *sensor case* frame **[Δθ ^{C}]**. An error model is provided that can be used to support analysis and design.



Each sensitive axis is modeled independently.

Press this button and Tapestry will randomly select the values in the controls by assuming the user-entered values represent a one-sigma

The Error Model is:

$$\Delta\theta^C = \Delta\theta^T + \beta + (1+\alpha)\Delta\theta^T + \varphi \times \Delta\theta^T + \sigma W$$

Where **[Δθ^T]** is the TRUE Delta Angle based upon the Truth data, **[Δθ^C]** is the Delta Angle in the *Case* frame output via the MFIO.

Noise (σ_W)

σ is the standard deviation of a Gaussian white noise process (W) used to apply jitter to the output Delta Angle. This error is typically due to sensor measurement electronics. These errors are applied per each case axis (x, y, z) in units of degrees per hour

$$1\ ^o/\text{hour} \approx 4.85 \times 10^{-6}\ \text{radians/sec}$$

Bias (β)

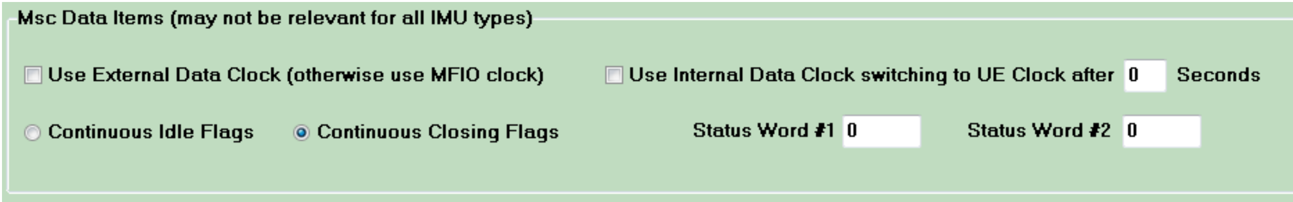
This value corresponds to the non-zero integrated vehicle rate measurement output for a zero applied input rate. The units are ^{o}/hour ≈ 4.85 x 10^{-6} radians/sec.

Scale Factor (α)

A non-zero scale factor causes the output Delta Angle to be in error proportional to the true input vehicle attitude rate input along the defined axis. The scale factor defines the proportionality constant. The input units are parts-per-million (PPM). 1 PPM = 1.0 x 10^{-6}

Misalignment (φ)

The gyro sensitive axes are mounted very accurately in an orthogonal triad in the *Case* axis, however there may be some small residual error in the alignment. This error causes a sensed attitude change to be projected into one of the cross orthogonal case axis. The input units are milli-radian or 0.001 radians.



Status Word 1 and 2

For the Honeywell and Litton SDLC sensors, a status word is output along with the navigation data. These fields are initialized to the appropriate default values. You may change the values if you desire. We point you to the appropriate sensor description documentation for the correct values required in these fields.

Idle Mode and Closing Flag Status

For the high rate Honeywell and Litton SDLC sensors, an opening and closing flag identify the beginning and termination of the navigation and autopilot data. This check box controls whether the sensor outputs continual closing flags when no inertial messages are scheduled for output.

Data Clock Options

The MFIO contains its own 1 MHz data clock. This can be used as the timing source for the output of the navigation and autopilot data. If required for your system, the MFIO can accept an external data clock from the host vehicle.

Check this if the UE sources the Data Clock →

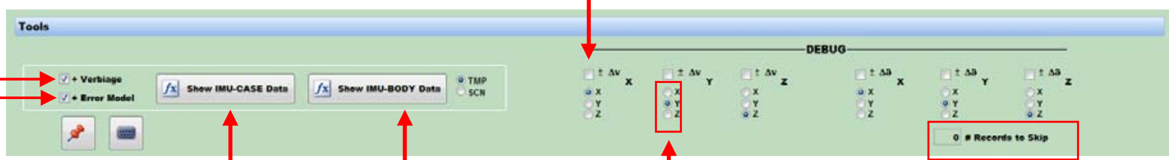
Very useful, we used these features extensively when debugging the IMU models.

Check to Switch Sign unconditionally

Dump-File Columns labeled if Checked

BINARY Output File Manipulations (for Debug)

Include Error Model in computations



Compute Output Delta Velocity and Delta Angle in IMU CASE Frame.
Uses the ADAPTATION PARAMETERS

Dumps to ASCII file

Select the Truth Component to enter into the selected Data slot. Eg. In the "x" structure store the "Y" value...

Binary output file can be positioned backward/forwards in intervals of ±0.01 sec

Compute Output Delta Velocity and Delta Angle in BODY Frame.
Does NOT use the ADAPTATION PARAMETERS.

Dumps to ASCII file