



## USING THE AUTOMOTIVE MODEL

In addition to the GPS Model, TAPESTRY provides an **Automotive Dead Reckoning** package based upon a triad of analog accelerometers and rate-gyro's. A Four-Wheel independent pulse generator provides distance traveled and attitude through differential wheel ticks. 10 Hz Serial data models emulate the SIRF-DRIVE-II Can-buss processing.

To use the Automotive Model, the Tapestry System must include the Multi-Function I/O Feature card [MFIO].



This document presents the modeling basis and operational description for the Tapestry **Automotive Dead Reckoning** simulation package. This package includes hardware and software upgrades to the basic Tapestry LabPro and SCS 3500 series Constellation Simulators.

To support multi-sensor GPS automotive products, the Tapestry system can be configured to generate voltages proportional to vehicle turn rate, acceleration, and ground speed. The simulator also provides serial data outputs at 1-10Hz that emulate proprietary **Dead Reckoning Serial Data** outputs in several formats.

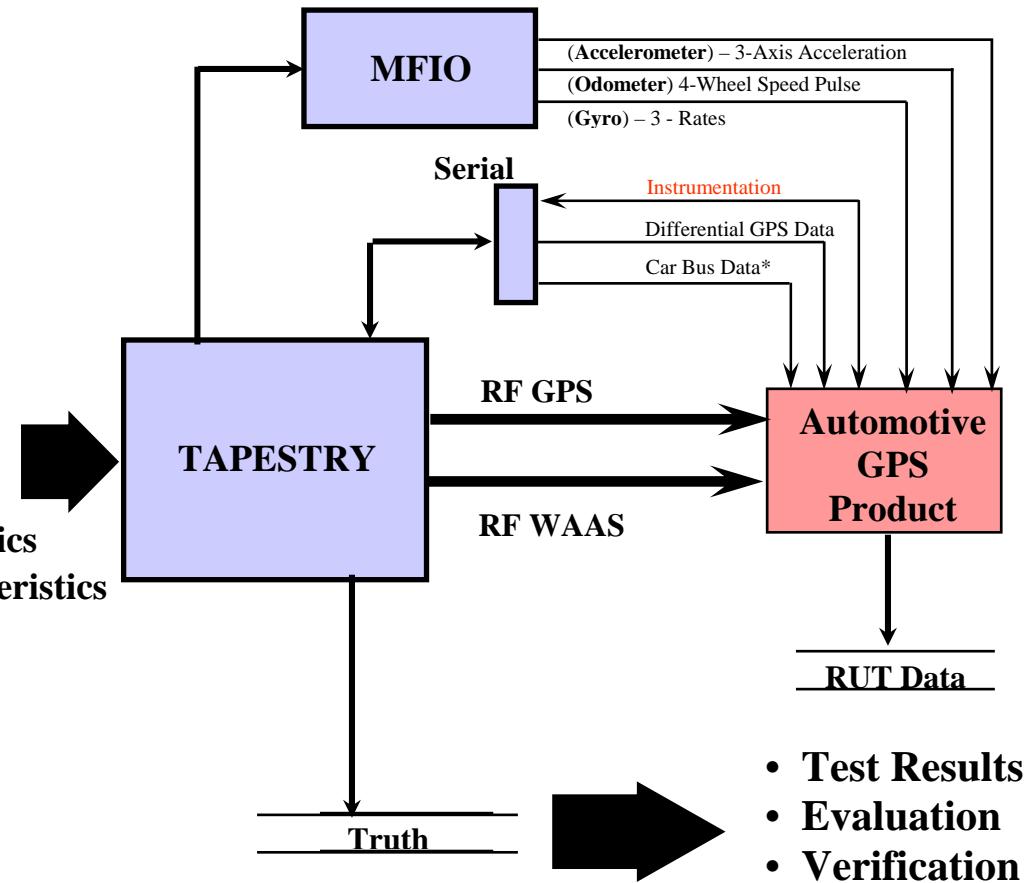
The Automotive package includes the following features:

- **3 Gyros:** 5 Volt analog outputs proportional to vehicle **Rate-of-Turn**. Proportionality factor and null rate offset are programmable. Nominally configured at 22.2 millivolts/ °/sec with a 2.5 Volt offset. The sense of the positive rate is programmable. Error models simulating noise, bias, scale factor, and non-linearity are provided. Independent programmable orientations.
- **Wheel Ticks:** Pulse rate output proportional to **Vehicle Speed**. Characteristics are: square wave programmable from 0 to 80,000 transitions per second. Error models simulating wheel slip, wheel sliding, bias, scale factor, and noise are provided. 4 Independent wheel channels provided with programmable wheel separation model.
- **Serial Data Messages:** Wheel Speed, Turn Rate, and other navigation data provided in serial format via PC Comport. 1 to 10 Hz rate supported in various formats.
- **3 Accelerometers:** 3 channels of 0-5 Volt accelerometer outputs are provided. Proportionality factor and null rate offset are programmable. Nominally configured at 600 millivolts/G with a 2.0 Volt offset. Error models simulating noise, bias, scale factor, and non-linearity are provided. Independent programmable orientations.
- **Programmable axle and wheel Base:** This support differential wheel ticks for inferring turn rate.



## ILLUSTRATION OF AUTOMOTIVE SIMULATION PACKAGE

- Vehicle Motion Profile
- Mission Plan
- GPS Characteristics
- WAAS Characteristics
- Gyro Characteristics
- Odometer Characteristics
- Accelerometer Characteristics
- Foliage, Multipath...



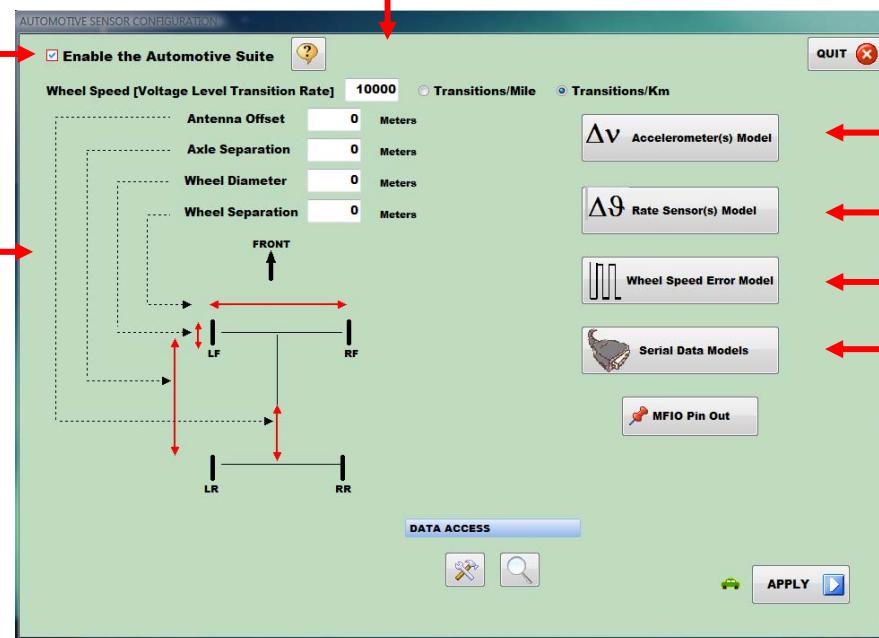


## SETTING UP THE SENSOR MODEL

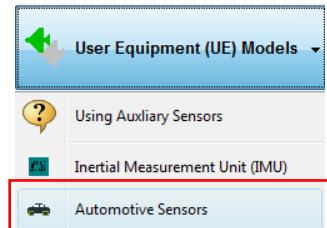
Access the Automotive Features from the User Equipment (UE) Models Menu located on the main Build Scenario screen:

You must enter a non-zero value into this field. In the general case, the wheel ticks cannot be of constant duty cycle because the vehicle speed is changing. This item specifies the transition rate of the wheel tick signal

Enable: [MFIO] required



Enter non-zero dimensions to incorporate Differential-wheel-ticks and Lever-arm effects



Accelerometer Triad

Rate-Sensor Triad

Distance Traveled Pulse Train Odometer

SiRFDrive-I/II  
RS232 Data Streams  
NMEA

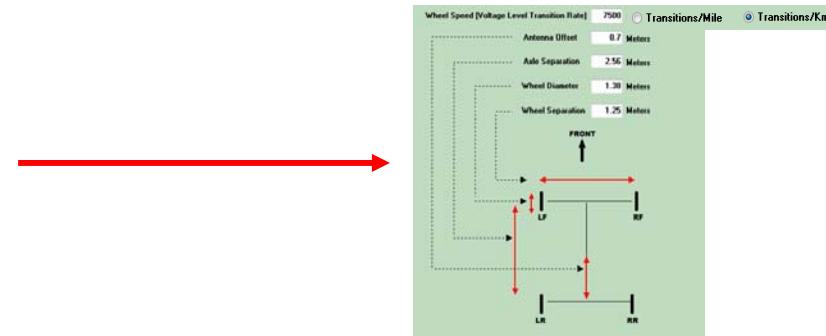
Select the sensor model you wish to configure. If you do not have a Multi-Function I/O [MFIO] expansion card installed in your system, Tapestry will protect the **Enable** control.



# WHEEL SPEED SENSOR

Tapestry provides 4 Wheel Speed outputs via the MFIO Feature card. The Output is in the form of a 5 VDC square waves each independently configurable and assigned to specific wheels. The only user parameter is the voltage transition rate. You can access the Front or Real Wheels [Left/Right] via the Pin Out [here](#).

Using the specified dimensions of the vehicle, Tapestry supports differential Wheel Ticks for turn rate determination.



Selection of the Wheel Speed Error Model presents a form in which you may change the default characteristics of the sensor, apply error effects, or setup scheduled “events” which cause anomalies in the output data. If these items are not changed the simulation will generate an exact value data stream. Note the Error model specified here, applies to **both** the Serial Data Output stream as well as the Hardware Pulse Output.

Values for each Wheel drawn independently.

To simulate the effects due to data transport and other delays relative to GPS-Time.

Schedule “Events” to simulate Wheel Slip / Slide etc.

**Applicable Wheel:** ALL WHEELS

**Wheel Speed Error Model [per selected wheel]:**

- Applied Noise  $\sigma$ : 0.00 M/s  $\sqrt{\text{Hz}}$
- Applied Bias: 0.00 m/sec
- Applied Scale Factor: 0.00 %
- Fixed Latency: 0.0 sec
- Random Latency  $\sigma$ : 0.0 sec
- randomize

**Wheel Speed Error-Event [per specified wheel]:**

- Event No.: 10
- Event Epoch: 0.0 Seconds into Sim
- Duration: 0.0 Seconds
- Pulse Bias: 0.00 Pulses
- Rate: 0 Pulses/Sec
- No Pulse Output

Buttons: Insert Event, Remove Event, Open Event File, APPLY



# WHEEL SPEED SENSOR

Tapestry models each wheel independently vis-à-vis the error model and special event schedule.

Use the pull down menu to select the applicable wheel for the error model parameters. If you want to combine wheels select “All Wheels” Tapestry will reset the error parameters you have specified such that the deterministic and random terms are forced equal.

## Hardware Error Model

The hardware generated Wheel Speed is a rate measurement. The associated error model applies as:

$$W_O = (1 + \alpha)W_T + B + \sigma_N \text{Gauss} + \Delta T_{FL} \dot{V}_A + \sigma_{RL} \dot{V}_A \text{Gauss}$$

## Serial Data Error Model

Output Serial Data can be one of two types: Rate or Distance-Traveled Data

For Rate Output:

$$W_O = (1 + \alpha)W_T + B + \sigma_N \text{Gauss} + \Delta T_{FL} \dot{V}_A + \delta T \sigma_{RL} \dot{V}_A \text{Gauss}$$

For Distance-Traveled Output:

$$D_O = (1 + \alpha)D_T + B + \sigma_N \text{Gauss} + \Delta T_{FL} \dot{V}_A + \delta T \sigma_{RL} \dot{V}_A \text{Gauss}$$

## Event Model

The Event Model consists of a time of applicability, Event Epoch, and Duration. During the event-interval they following effects can be applied:

Pulse Bias	0.00 Pulses	Rate	0.00 Pulses/Sec	<input type="checkbox"/> No Pulse Output
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Pulse offset by this amount during Event Interval  $\Delta T$

Pulse output changes by this rate during  $\Delta T$ . This simulates Wheel Spin.

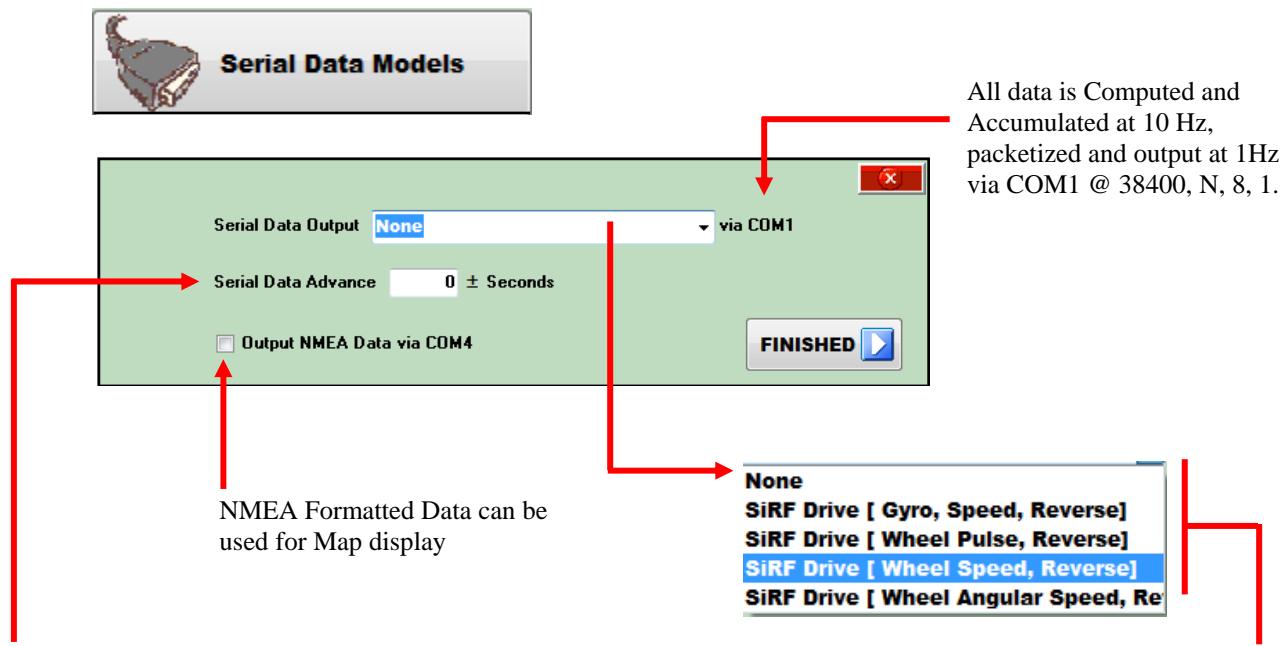
No pulses output for the interval  $\Delta T$ . This simulates Wheel Slip



## SERIAL DATA MODELS

Serial Data is provided at 10 Hz to emulate the outputs of the CAN-Type data packages. We provide the following Serial outputs that satisfy all the data types associated with the SiRFDrive I and II systems.

All composite serial data is output to COM1 located [here](#) on the Simulator Chassis back panel.



Nominally Serial Data is output “on-time” coincident with the GPS based timing mark.

To ADVANCE, enter a (-) value into this field. This will cause the output data to be in the *future* by the entered amount of time (in 100 millisecond increments).

To DELAY, enter a (+) time into the field. This will cause the data to be in the past by the entered time increment.

(*100 milliseconds resolution*)

Four SiRFDrive Outputs are provided. The SiRF protocols are proprietary; consult your SiRF developers’ kit documentation for the details.



## Δθ Rate Sensor(s) Model

The gyro model is used to generate an analog voltage output along three axis and for constructing the appropriate serial data messages.

ROTATION-RATE SENSORS

Turn Rate Voltage Scaling    22.2 milli-volt/ °/ sec  
Zero Rate Voltage Offset    2.5 Volts

QUIT

ROTATION-RATE CASE-TO-BODY ORIENTATION

Roll-Gyro Sensing-Axis Orientation	Azimuth: 0 °	Elevation: 0 °
Pitch-Gyro Sensing-Axis Orientation	Azimuth: 0 °	Elevation: 0 °
Yaw-Gyro Sensing Axis Orientation	Azimuth: 0 °	Elevation: 0 °

ROTATION-RATE ERROR MODEL

randomize

White Noise	ROLL: 0 ° / sec /√Hz	PITCH: 0 ° / sec /√Hz	YAW: 0 ° / sec /√Hz
Bias	ROLL: 0 ° / sec	PITCH: 0 ° / sec	YAW: 0 ° / sec
Ramp	ROLL: 0 ° / sec <sup>2</sup>	PITCH: 0 ° / sec <sup>2</sup>	YAW: 0 ° / sec <sup>2</sup>
Scale Factor	ROLL: 0 %	PITCH: 0 %	YAW: 0 %
Correlated Noise	ROLL: 0 °/ sec	PITCH: 0 °/ sec	YAW: 0 °/ sec
Noise Time Constant	ROLL: 1 Seconds	PITCH: 1 Seconds	YAW: 1 Seconds

[R] Roll-Axis Non Orthogonality     $\theta_{RP}$ : 0 milliradian     $\theta_{RY}$ : 0 milliradian  
[P] Pitch-Axis Non Orthogonality     $\theta_{PR}$ : 0 milliradian     $\theta_{PY}$ : 0 milliradian  
[Y] Yaw-Axis Non Orthogonality     $\theta_{YR}$ : 0 milliradian     $\theta_{YP}$ : 0.0 milliradian

Flip (Sign Convention)     Y     P     R

### Turn Rate Voltage Scaling

This value controls the transformation from °/Sec of turn rate to voltage output on the D2A expansion card. By default the setting is 22.2 milli-volts/ Degree/second. A positive voltage above the zero-point offset corresponds to a clock-wise rotation. To switch the sense, see using the A2DCONFIG file in section 3.

### Zero Rate Voltage Output



For a typical turn rate gyro, 0 angular rate does not correspond to 0 output voltage. Typically the sensor outputs the maximum (counter-clockwise) turn rate at 0 volts and the maximum (clockwise) turn rate at 5.0 volts. The default setting is 2.5 volts at 0 °/second. To change the calibration of the 0-level see using the A2D.CONFIG file in section 3.

### Sensitive-Axis Orientation

Enter the Elevation angle (deg) and Azimuth angle (deg) for the sensitive axis of the rate gyro. 0° Elevation and 0° Azimuth corresponds to a FORWARD (along vehicle front) accelerometer. Elevation angle is positive up.

### Rate Gyro Error Parameters

The error model for the gyro is controlled by the values input in the following data items.

#### Applied Noise

This value is interpreted as a one-sigma standard deviation used to scale a gaussian random number sequence. White noise is applied to the vehicle turn rate.

$$\text{Output Rate} = \text{True Rate} + \text{Applied}_\text{Noise} * \text{gauss}()$$

The value is input in °/Sec and computed at 10Hz.

#### Bias

This input provides a fixed offset to the output gyro turn rate. Note that this value is not interpreted as a standard deviation but is used directly as the applied rate bias.

$$\text{Output Rate} = \text{True Rate} + \text{Bias}$$

The value is input in °/Sec.

#### Bias Ramp

This value ramps the gyro drift over time. As is the case for the gyro bias, this value is directly applied to the gyro drift and is not interpreted as a standard deviation.

$$\text{Output Rate} = \text{True Rate} + (\text{Bias} + \text{Bias}_\text{Ramp} * \Delta T)$$

The value is input in °/Sec/Sec.



## Scale Factor

This value is used to apply an offset to the output turn rate based upon the magnitude of the applied vehicle turn rate. This value is applied directly and not used as a standard deviation.

$$\text{Output Rate} = \text{True Rate} * (1.0 + \text{Scale\_Factor})$$

The value is input in %.

## Correlated Noise and Time

These parameters control a first order Gauss-Markov process. The error model is of the form

$$\partial R / \partial t = -R/\tau + \sigma W$$

Where  $W$  is a white noise process scaled and computed at 10Hz.

### 2.2.4 Gyro Error Model and Computation Method

The following algorithm is used to compute the output data content for the turn rate analog channel.

True turn rate ( $R_T$ ), derived from continuous vehicle linear and angular jerk, acceleration, and velocity, is generated at 10Hz within the main simulation program element. The true turn rate can be deterministically corrupted using the following error model;

$$R = (1 - \alpha) R_T + \beta + \eta * G(\text{seed}) + \eta_C$$

- i. Gyro Bias ( $\beta$ ). This is entered in degrees/second and applied directly to the true turn rate.
- ii. White noise( $\eta$ ). Entered in °/s and used directly as a multiplier for a 10Hz gaussian random noise process  $G(\text{seed})$ .
- iii. Scale factor ( $\alpha$ ). Entered in % and used to decrease/increase the turn rate proportionally.
- iv. Correlated noise ( $\eta_C$ ). Scales a 1<sup>st</sup> order gauss Markov process. This error component can be used to simulated effects from residual temperature calibration error or to effectively provide a slowly time-varying gyro bias component.

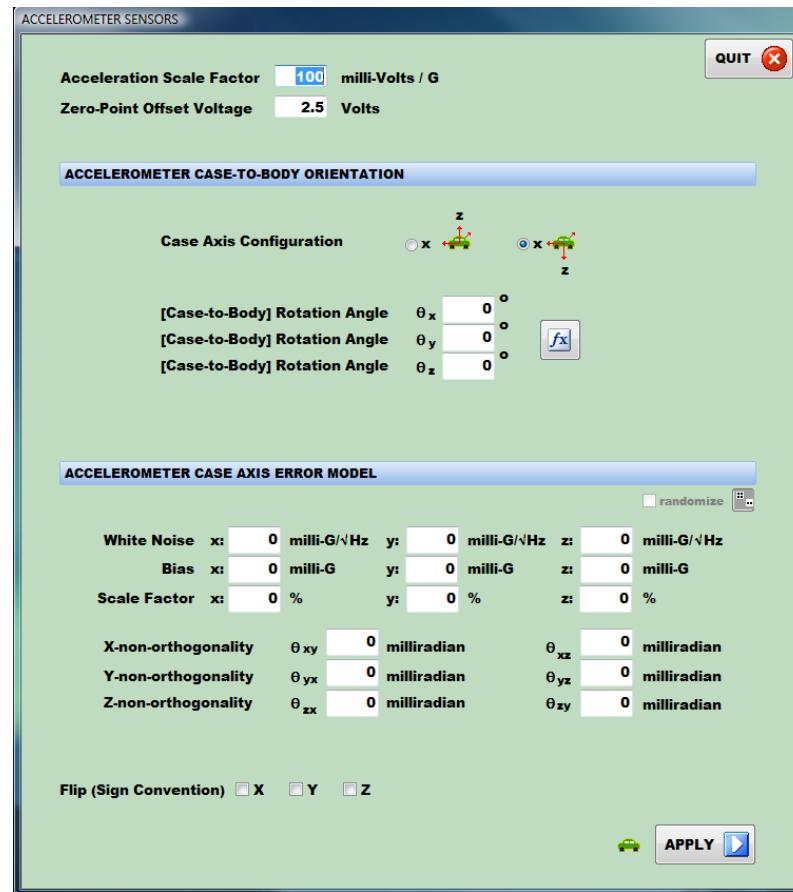
These error models, were appropriate, are driven with a random seed. If the seed is initialized to zero the PC clock seeds the gaussian random number generator and each *build* (not execution - which is repeated exactly each time!) of the simulation results in another error ensemble. If non-zero, the seed causes the error ensemble to be deterministic.



## ΔV Accelerometer(s) Model

### 2.2.5 Accelerometer Sensor Model Setup and Configuration

Tapestry incorporates three (3) analog accelerometers. The user entries are defined below with the output characteristics and orientation established by the user.



The accelerometers are accessed independently along three sensitive axes. The Tapestry user defines the orientation of the sensitive axis by entering an Azimuth (measured clockwise from the FRONT of the vehicle) and Elevation (measured up from the FRONT and RIGHT vehicle axis).



## Sensed Acceleration Scale Factor

This value scales the sensed acceleration into a voltage output. Typically a positive (forward) acceleration results in a positive voltage above the zero-point offset. A negative (reverse) acceleration generates a decreasing voltage relative to the zero-point offset.

A lateral acceleration to the right produces a voltage above the zero-point offset. Acceleration to the left produces a decreasing voltage relative to the zero-point offset.

## Zero Point Offset

To sense both directions of acceleration a zero point offset is required. Typically 2-3 volts corresponds to no sensed acceleration.

## Body Alignment

Enter the Azimuth (CW from vehicle FRONT) in Degrees and Elevation angle (+ up from FRONT). A forward pointing accelerometer would have a sensitive axis defined by 0° Azimuth and 0° elevation.

## Accelerometer Error Model

The model simulates three independent accelerometers that measure vehicle acceleration and express the result in the vehicle sensor frame. Any acceleration dynamic range can be simulated with the LSB derived from the 12-bit mechanization of the function card. Typically  $\pm 2G$ 's is the maximum acceleration.

The error model equations for the output of the vehicle incremental velocity (acceleration) along each axis are;

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

Where  $\Delta v^T$  is the TRUE delta velocity based upon the simulated vehicle truth data,  $\Delta v^M$  is the IRU-measured delta velocity output via the IRU expansion card. The remaining terms are defined as follows:

## Noise ( $\sigma W$ )

$\sigma$  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. These errors are applied per each case axis (x-forward, y-right, z-down) in units of micro G ( $\mu g$ ). A micro-G is given by

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

## Bias ( $\beta$ )



This value corresponds to the non-zero accelerometer measurement output for a zero applied acceleration input. The units are  $\mu\text{g}$ 's with  $1 \mu\text{g} \approx 0.00001 \text{ m/s}^2$

**Scale Factor (  $\alpha$  )**

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 scale factor defines the proportionality constant. The input units are parts-per-million (PPM).  $1 \text{ PPM} = 1.0 \times 10^{-6}$

### Misalignment ( $\phi$ )

The accelerometers are mounted perfectly in an orthogonal configuration along the IRU case sensitive axis. However there is always some small residual error in the alignment. This error causes a sensed acceleration to be projected into one of the cross orthogonal case axis. This item simulates this effect with the input units being milli-radian or 0.001 radians.

### Least Significant Bit effects (LSB).

This is a very *important* component of the error model. This effect results from scaling of measured velocity increment into a data length compatible with the data interface specification. There are no user entered parameters as the LSB error is fixed by the interface specification and dynamic range specified by the user.

## 3.0 Configuration of the Dead Reckoning Upgrade Package

The Automotive package is an optional add-on to the Tapestry Windows software delivered with the Navigation Laboratories LabPro constellation simulators. The automotive package is a turn-key system including all of the following elements:

- Tapestry Windows Automotive Software package. The software replaces the scenario building and run-time applications described in the Tapestry Windows Users Manual. This software includes a 1 year support and upgrade privileges
- MFIO PCI function generation card. This expansion card and software device driver is used to generate 4 variable analog channels and 4 discrete pulse channels (wheel speed pulse train). The output connector is a DB25.
- Comprehensive instruction manual and optional training.



## Multi-Function Input/Output (MFIO) – DB25M Pin Out Automotive Configuration

FUNCTION	PIN
Reverse	20
Yaw Gyro	21
Roll Gyro	12
Pitch Gyro	24
X-Accelerometer	9
Y-Accelerometer	22
Z-Accelerometer	25
Ground	11
Left Front	18
Right Front	6
Left Rear	19
Right Rear	7
R Table ±10VDC, 200 mA +	5
R Table ±10VDC, 200 mA -	8

