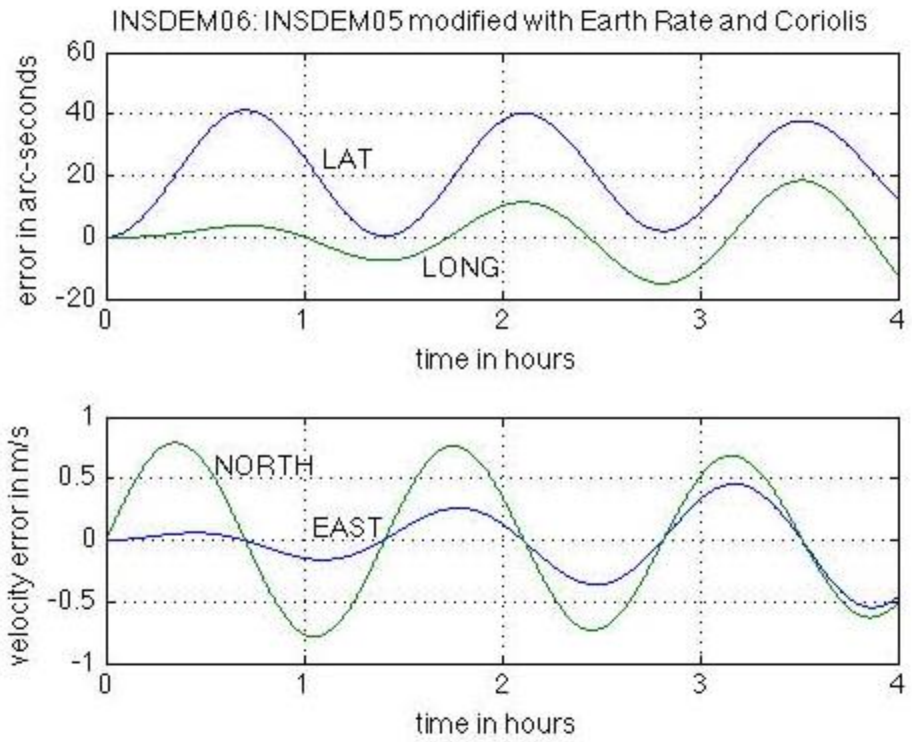
INS Toolbox 3.0



The INS Toolbox provides the necessary functions to emulate a wide variety of inertial sensors from RLG's and FOG's down to MEMS sensors via user-defined sensors errors such as biases, scale factor error and noise.

A key feature is the F-16 six degree-of-freedom (6DOF) trajectory generator with simulated feedback control. This greatly enhances the fidelity of the simulated trajectories as well as that of the simulated inertial sensor outputs. The toolbox contains functions that allow the user to define a dynamic trajectory in a local-level coordinate frame and then perform a full INS simulation in the rotating earth frame.

The INS Toolbox is fully compatible with the GPSoft SatNav Toolbox and both are utilized in GPSoft's Navigation System Integration & Kalman Filter Toolbox.

The links below provide examples:

- F-16 6DOF Flight Profile Generator Feedback Control
- Automobile Profile Generator
- Local Level INS Simulation
- Quaternion Updating
- Sensor Error Simulations
- Great Circle Path Generator
- Great Circle Path INS Simulation Sensor Errors
- Wander-Azimuth-Mechanizations

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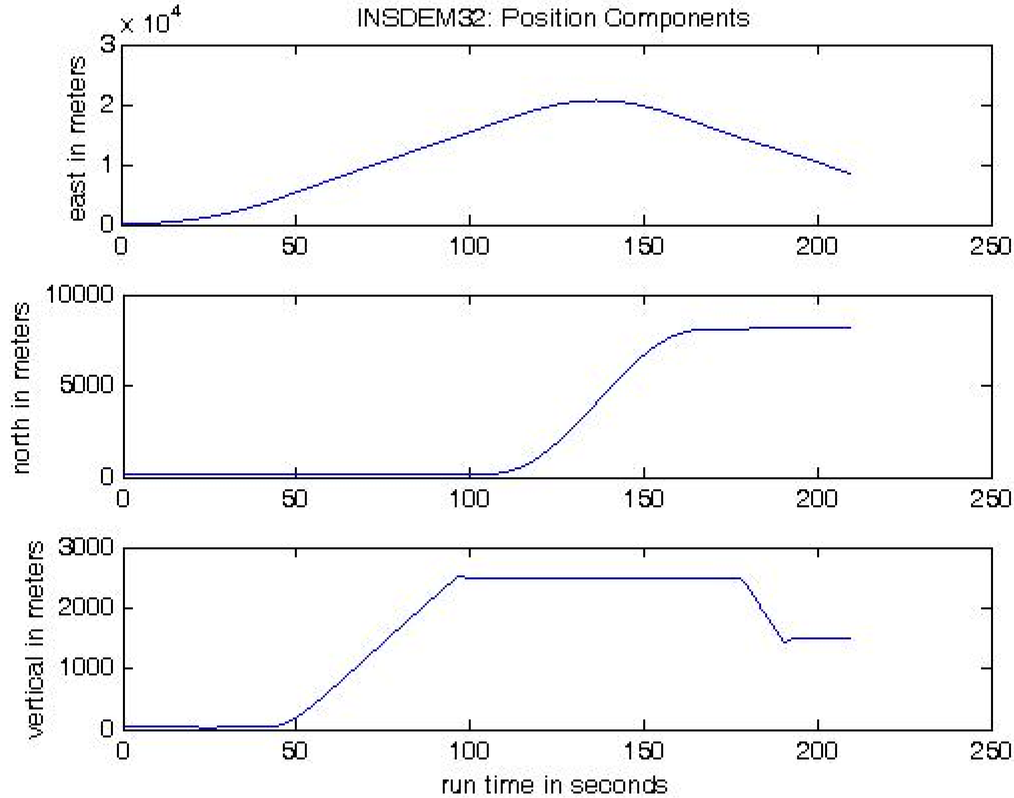
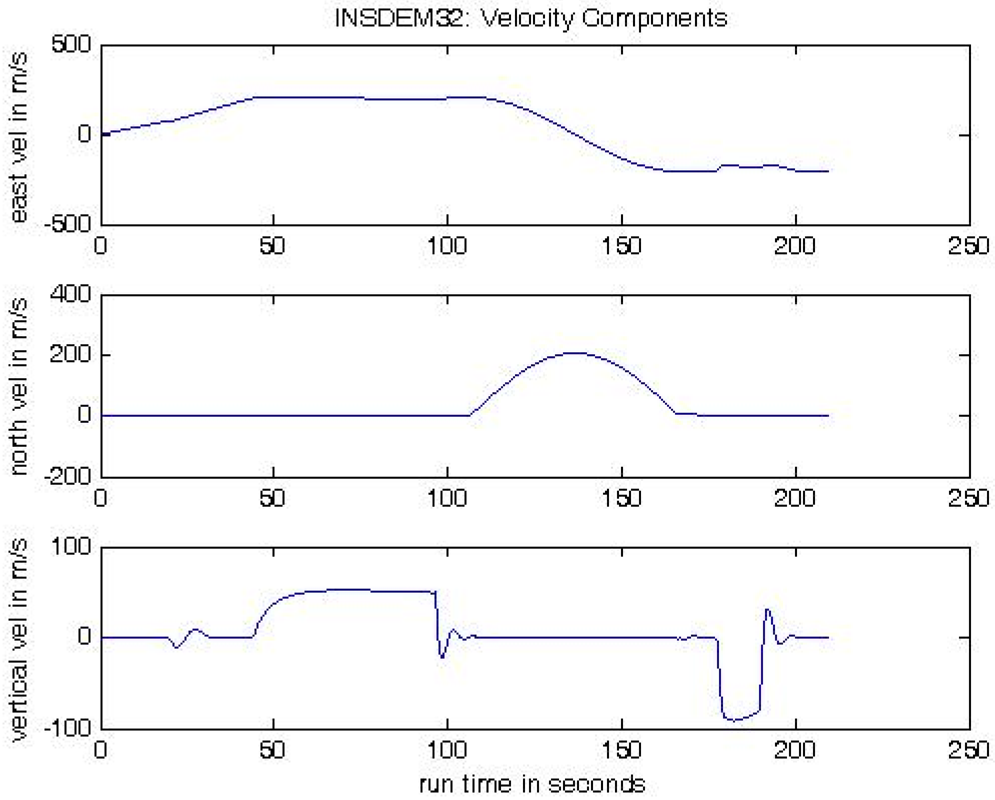
F-16 6DOF Flight Profile Generator with Feedback Control

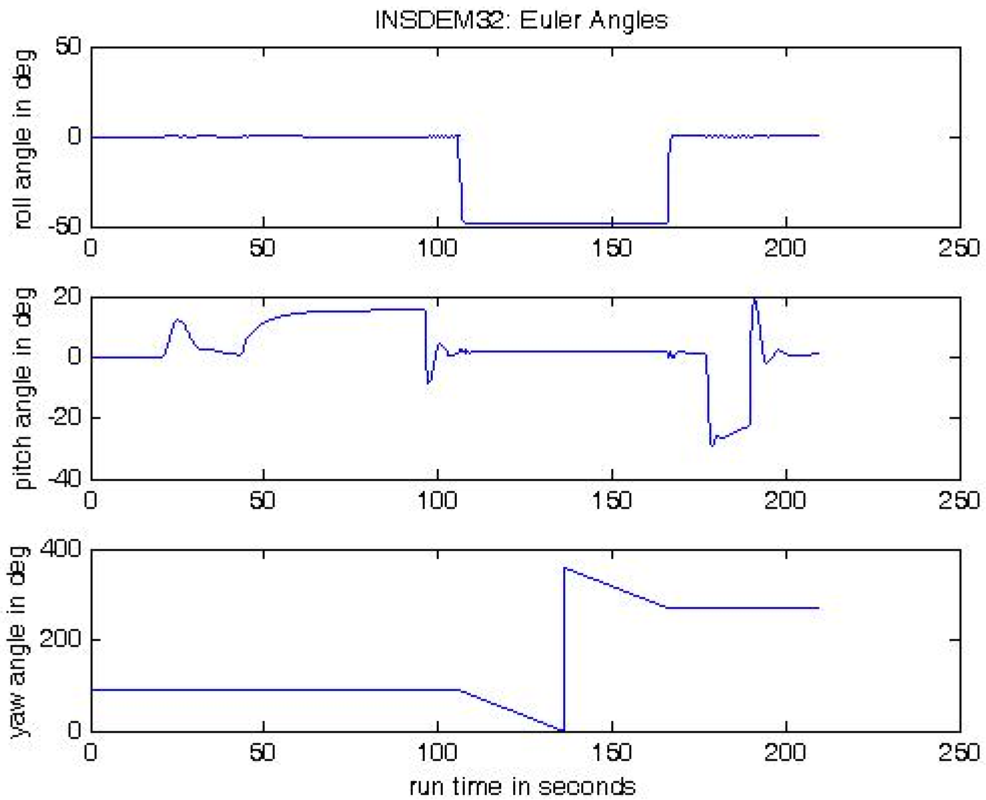
The toolbox function PROFILEF16 generates F-16 flight profiles based on the simplified non-linear 6DOF model presented in the book "Aircraft Control and Simulation," 2nd edition, by B. Stevens and F. Lewis, published by Wiley, Hoboken, NJ, 2003. Position (shown above), velocity, and body angles, (shown below) are all generated. With PROFILEF16 the user can specify all the usual autopilot modes such as altitude hold (with acceleration/deceleration to a desired velocity), climbs/descents to a desired altitude and coordinated turns to a desired heading. The function generates paths in a locally-level coordinate system. Additional functions are provided to allow the user to convert to a rotating earth-referenced coordinate system.



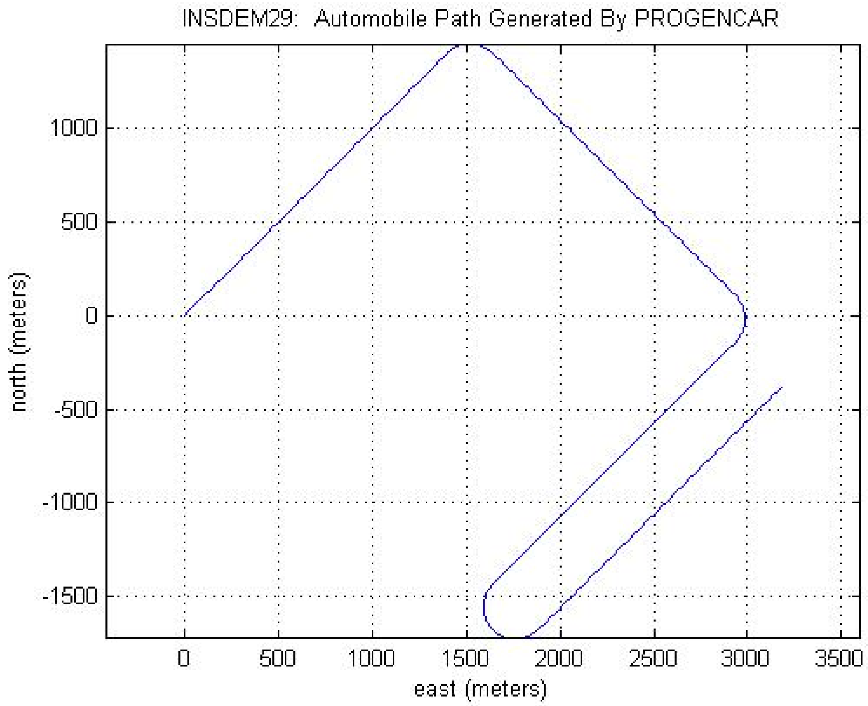
Velocity Components


INSDEM32: Velocity Components
east vel in m/s
north vel in m/s
vertical vel in m/s
run time in seconds
500
0
-500
400
200
-200
100
-100
50
150
250

Body Angles:

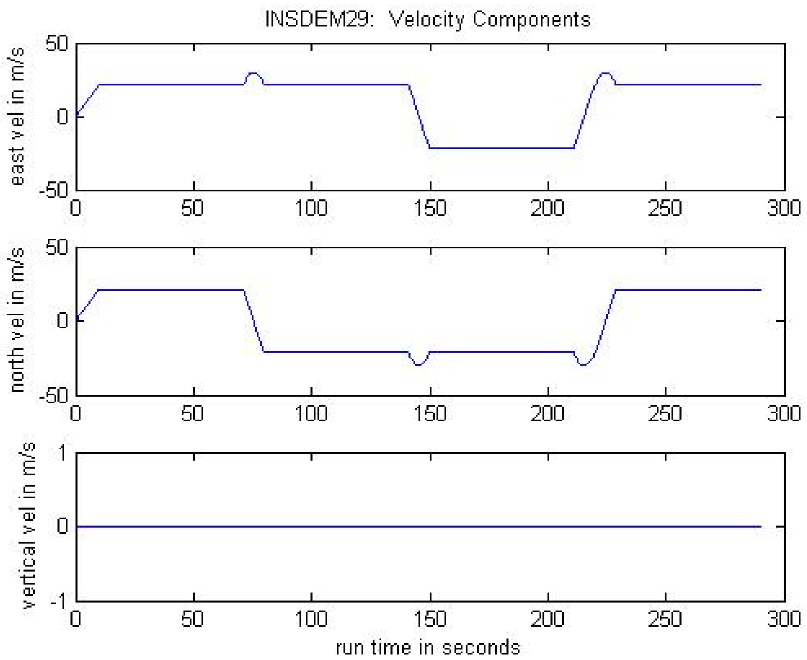

INSDEM32: Euler Angles
roll angle in deg
pitch angle in deg
yaw angle in deg
run time in seconds
50
0
-50
20
-20
-40
400
200
100
150
250

Automobile Profile Generator

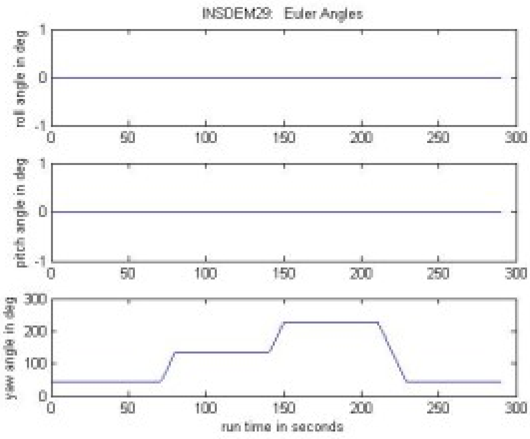


The toolbox function PROGENCAR generates land vehicle profiles. Position (shown at right), velocity, and body angles, (shown below) are all generated. With PROGENCAR the user can specify straight segments with constant velocity or constant acceleration and can generate constant radius turns. Paths are generated in a horizontal plane. The function generates paths in a locally-level coordinate system. Additional functions are provided to allow the user to convert (shown below) to a rotating earth-referenced coordinate system.

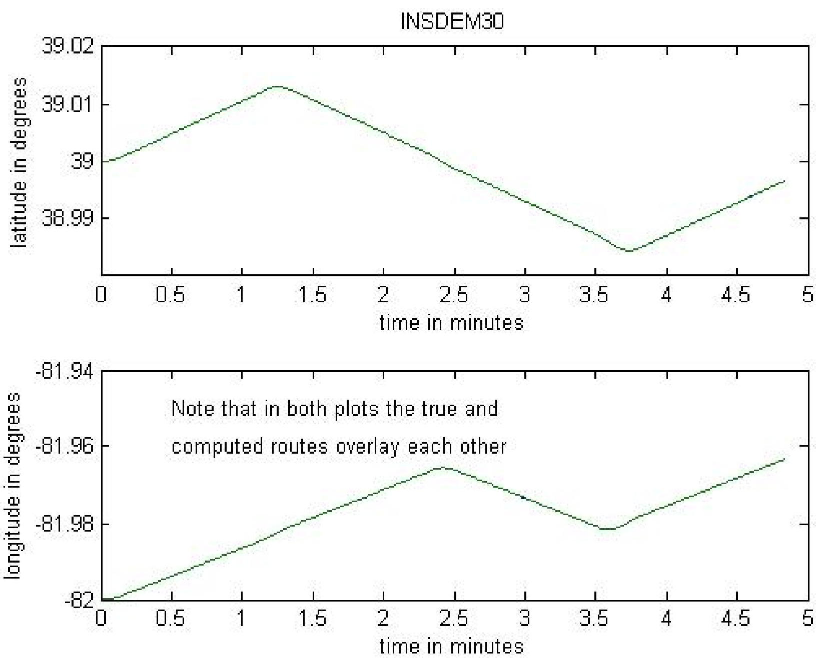
Velocity Components:



Body Angles (Euler Angles)

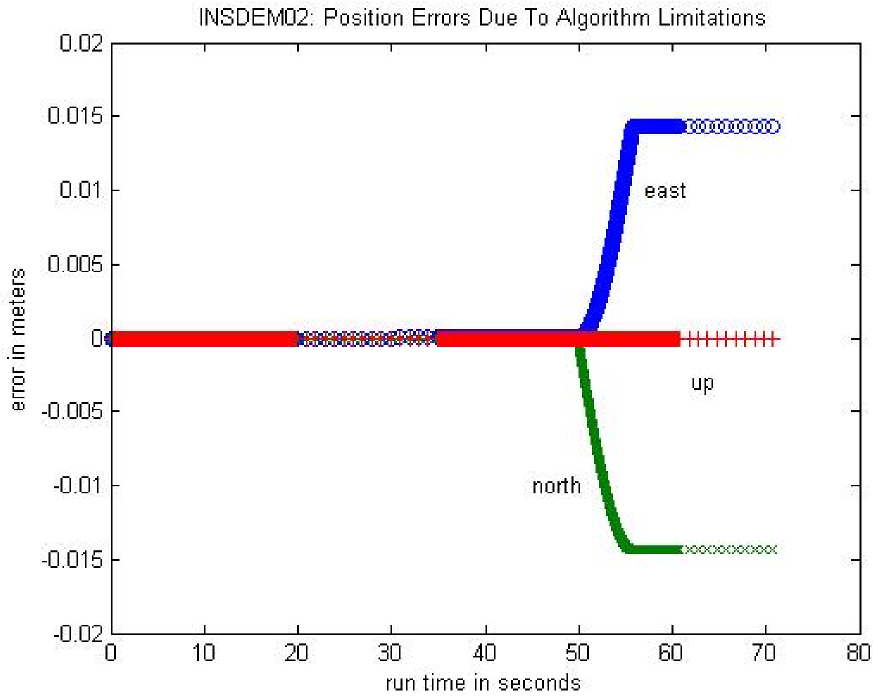


Converting to Rotating Earth-Rotation Coordinates



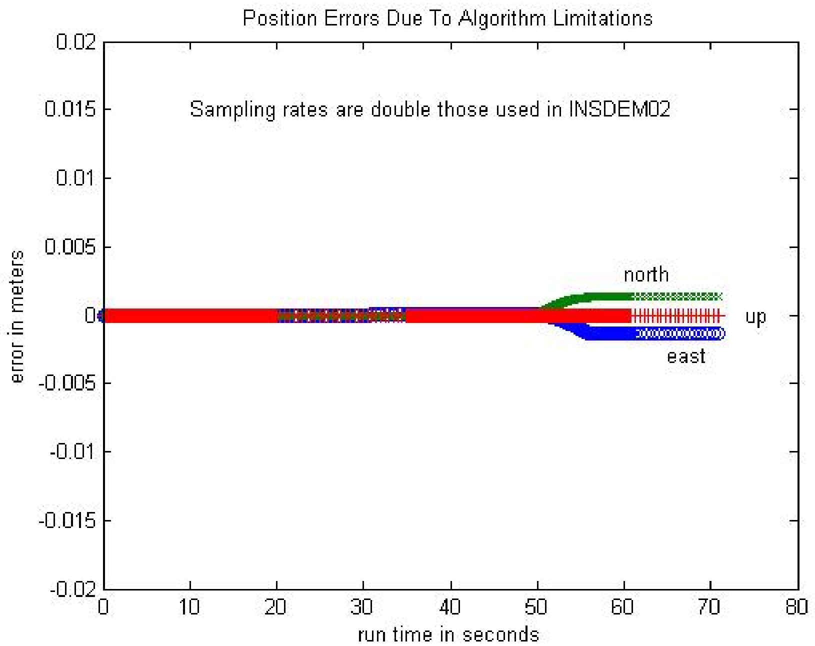
Local Level INS Simulation

As an introduction to the capabilities of the INS Toolbox, consider a simplified three-dimensional INS simulation. The toolbox function PROGEN generates three-dimensional flight profiles in a locally level coordinate system. The toolbox functions GENDV and GENDTHET take the output of PROGEN and generate ideal, error-free delta-V's and delta-theta's (note that these are the components due to vehicle motion relative to the local-level coordinate frame only. Earth rotation and Coriolis effects are handled separately. See the sections on sensor error simulations and great circle path simulations: Error-Free and with Sensor Errors).



The inertial processing of the "measurements" first involves initializing position, velocity and attitude. For the moment we will assume that the initialization has been accomplished without error. The next steps (which are performed for each measurement epoch) involve 1) using the toolbox function BODUPDAT to update the body-to-nav direction cosine matrix (attitude representation); 2) using the updated direction cosine matrix to translate the delta-V's from the body-frame to the local-level frame; 3) accumulating the translated delta-V's to update velocity and 4) integrating velocity to update position.

A demo program which performs the aforementioned tasks is provided with the toolbox. On a global scale, the result of the inertial processing is virtually identical to the original flight profile. There are errors, however, due to imperfect integration. The errors are small but measurable:



It is apparent from the plot that multiple sampling rates were employed. Staight segments do not need to be sampled as often as turns and other dynamics and the toolbox supports multi-rate simulations. Another example given in the toolbox is a repeat of the above example but with time steps cut in half. The results, as expected, are better:

Quaternion Updating:

The toolbox supports the representation and updating of attitude through quaternions as well as direction cosines. The toolbox provides the following functions:

- QUAUPDAT – Update quaternion body-to-nav attitude vector
- QUAMULT – perform quaternion multiplication
- QUA2DCM – convert from quaternion to direction cosine matrix
- EULR2QUA – convert from Euler angles to quaternion
- DCM2QUA – convert from direction cosine matrix to quaternion

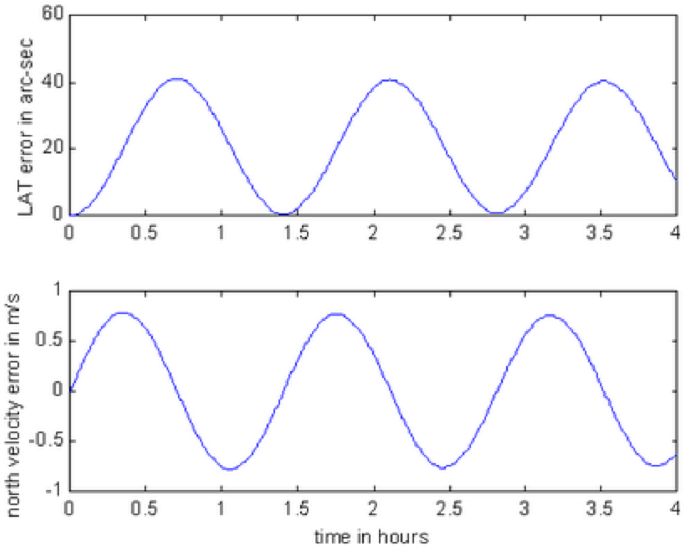
Sensor Error Simulations

In addition to the local-level simulations supported by the toolbox, full simulations including the effects due to navigation over a rotating, spherical earth are also supported. Consider the following example simulations produced with the toolbox:

Single-Channel Simulation with Accel Bias:

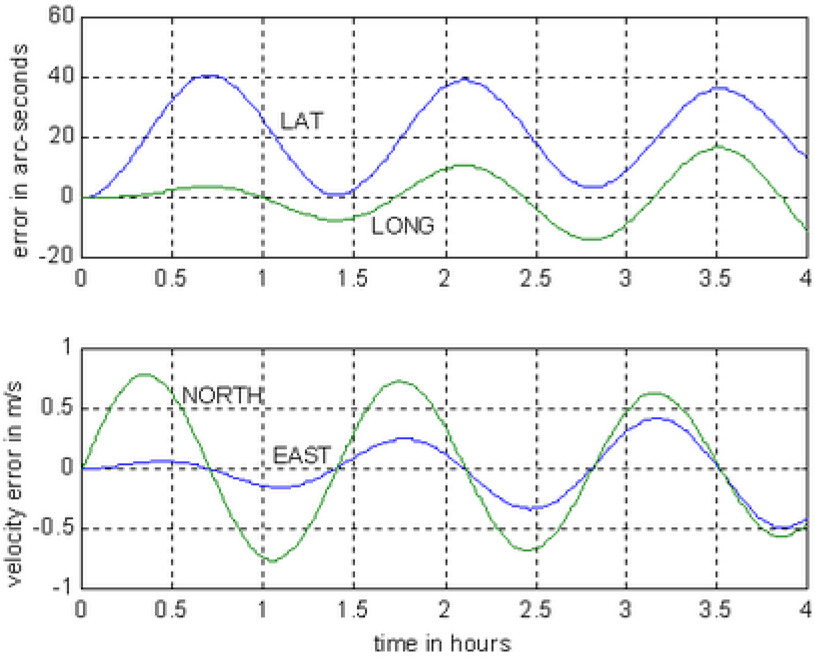
INSDEM05 is a demo included in the toolbox which performs a single channel simulation. A static vehicle is located at 45 degrees north latitude and is pointed north. A 100 micro-g bias is placed on the north accelerometer. The result of the simulation is:

According to theory, velocity error as a function of accelerometer bias is a zero-mean sinusoid with a peak value of 0.026 feet/sec per micro-g of accel bias. For 100 micro-g, then, the peak velocity error should be approximately 2.6 feet/sec or 0.8 m/s. This is observed to be the case in the above plot. Similarly, theory says that the position error should be a biased sinusoid ranging from zero up to a peak value of 0.007 nautical miles per micro-g. In this case the peak should be 0.7 nautical miles which corresponds approximately to 42 arc-seconds. Again, this is observed to be the case in the plot.

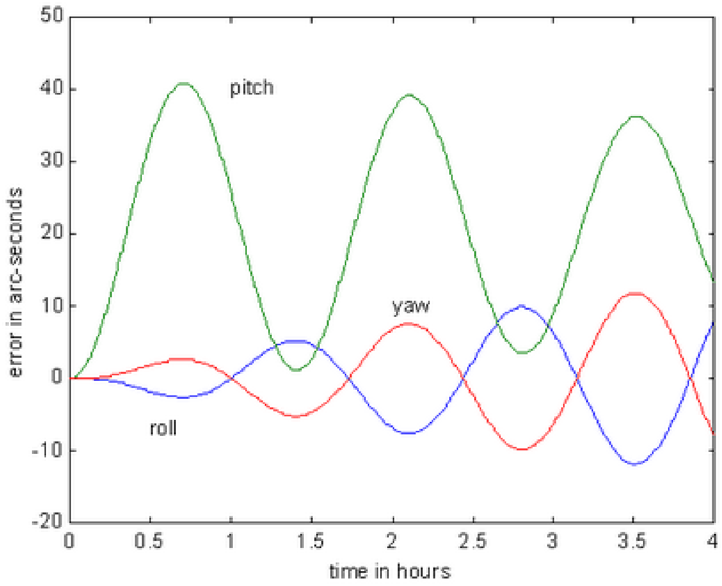


3-D Simulation with single accel bias: Accelerometer Bias Simulation

INSDEM06 is a demo included in the toolbox which extends the single channel simulation of INSDEM05 to a full three dimensional simulation. Again, a static vehicle is located at 45 degrees north latitude and is pointed north. A 100 micro-g bias is placed on the north accelerometer. The result of the simulation shows the cross-coupling effects:

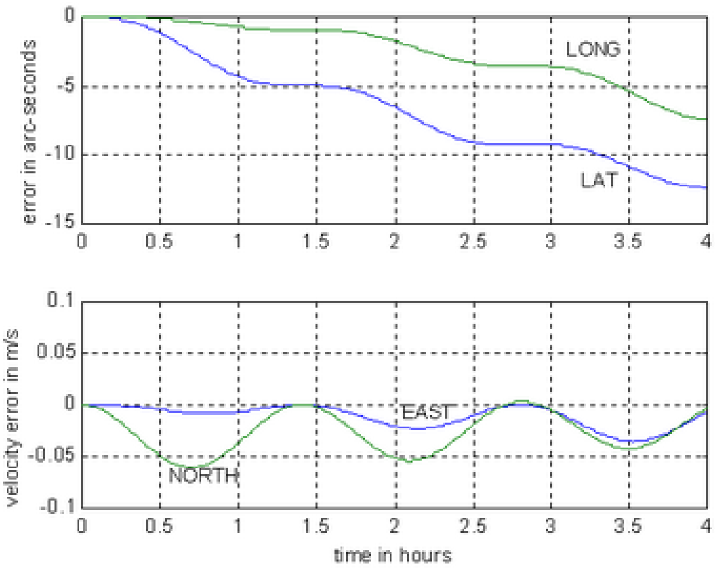


Errors can also be observed in the computed attitude. The pitch error is dominant as would be expected with a north accel bias on a vehicle pointed north. However, the error couples into the other two axes as well:

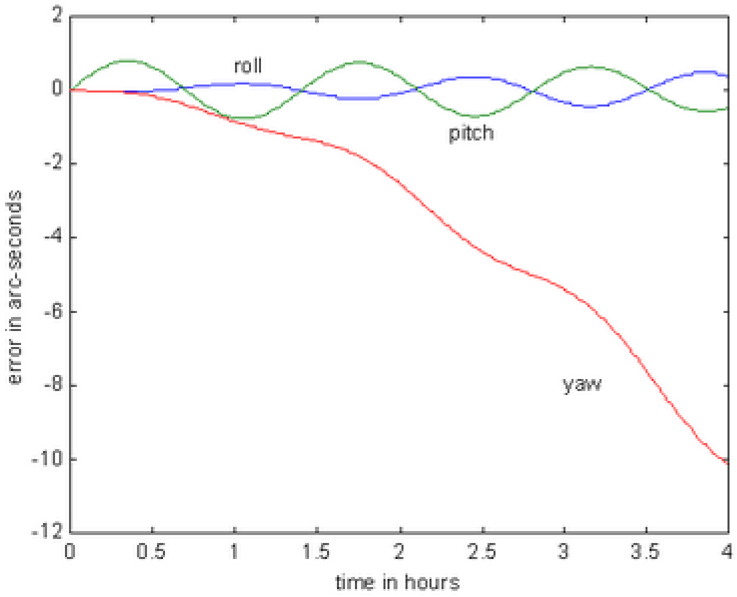


3-D Simulation with single accel bias: Gyro Bias Simulation

A static vehicle is located at 45 degrees north latitude and is pointed north. A bias of 0.001 degree/hour is placed on the east gyro. The Schuler oscillations are present in addition to a long term drift.

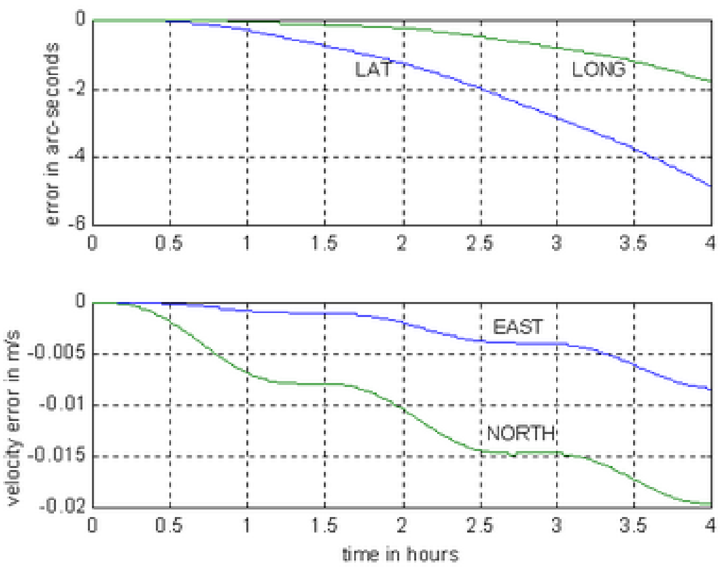


As might be expected, this is also the case with the yaw error:

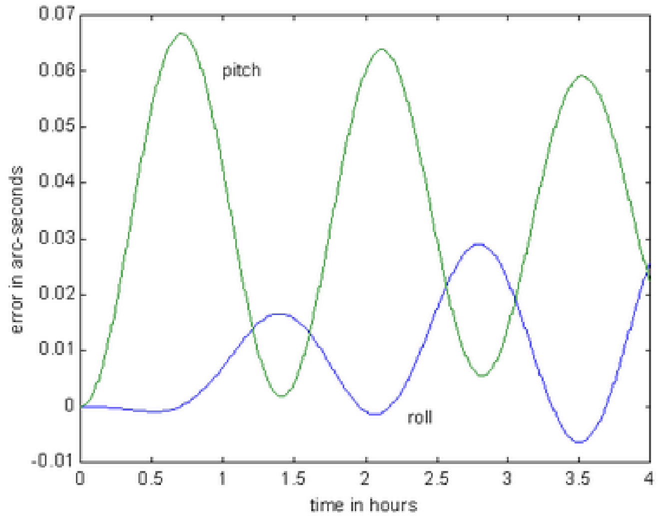


3-D Simulation with single accel bias: Vertical Gyro Bias Simulation

A static vehicle is located at 45 degrees north latitude and is pointed north. A bias of 0.001 degree/hour is placed on the down (i.e., vertical) gyro:

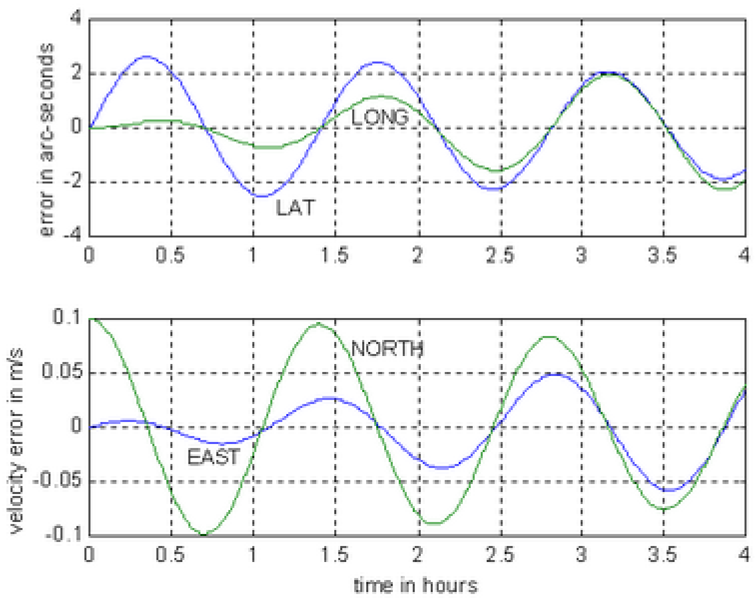


Pitch and roll are affected through cross-coupling of the vertical gyro error:

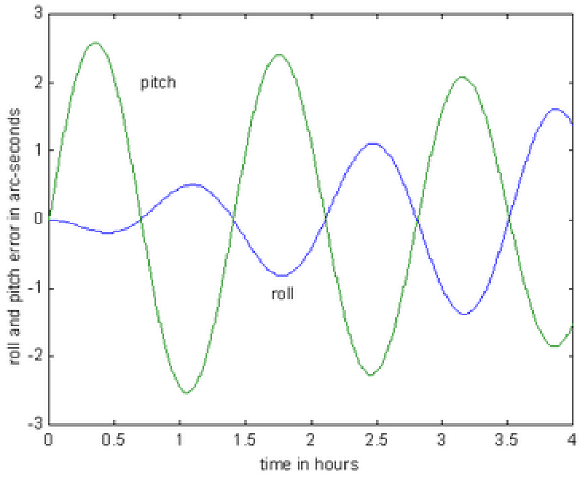


3-D Simulation with single accel bias: Initial Velocity Gyro Bias Simulation

A static vehicle is located at 45 degrees north latitude and is pointed north. An initial north velocity error of 0.1 m/s is placed on the north channel:

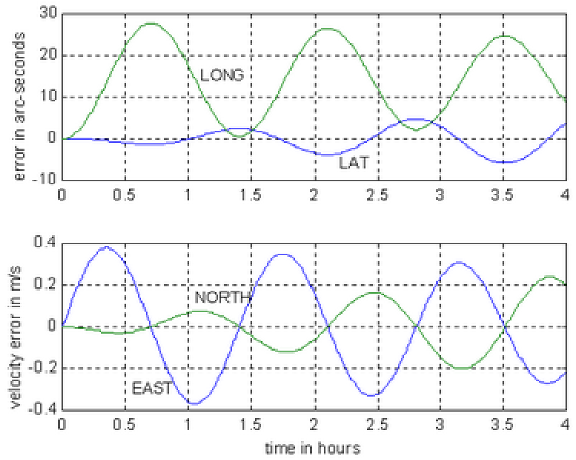


Pitch is impacted immediately and eventually the roll catches up:

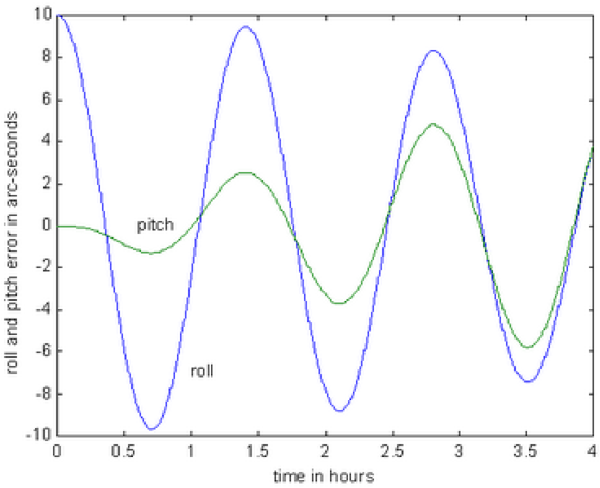


3-D Simulation with single accel bias: Initial Attitude Error Simulation

A static vehicle is located at 45 degrees north latitude and is pointed north. A 10 arc-second initial tilt (error) is placed on the north axis:

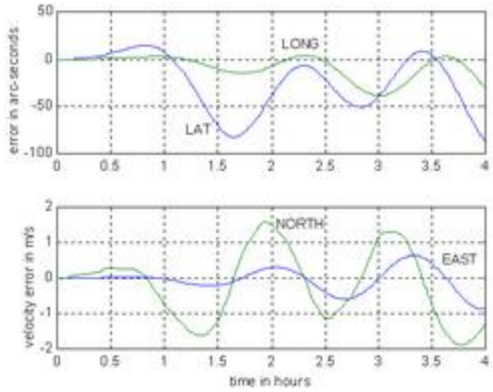


Pitch error starts off at 10 arc-seconds given the initial condition. Eventually the pitch error catches up:

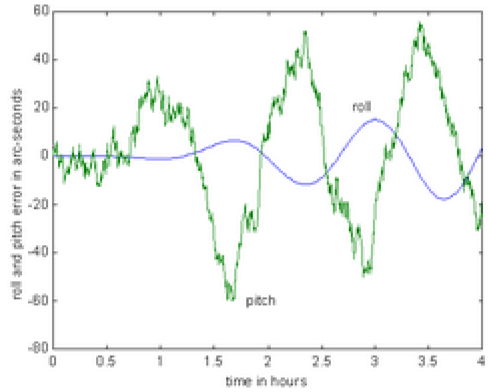


3-D Simulation with single accel bias: Gyro White Noise Simulation

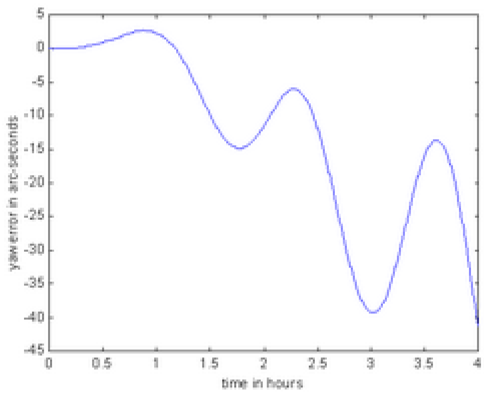
A static vehicle is located at 45 degrees north latitude and is pointed north. Gyro white noise with standard deviation of 0.01 degree/root-hour is placed on the east gyro only. Position and velocity errors grow as expected:



Pitch error is quite noisy which is to be expected since the vehicle is pointed north and thus the east gyro directly affects pitch. Roll and yaw errors are smooth since they are affected indirectly by the east gyro error:

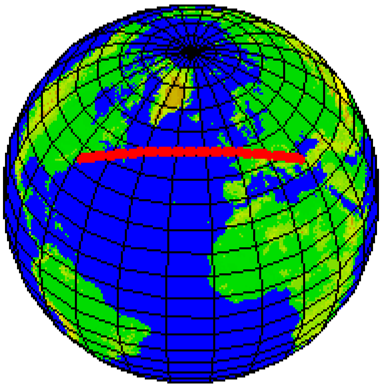


Yaw error experiences a drift in addition to the Schuler oscillations:



Great Circle Path Generator

The function GREATCIR generates great circle paths between two points on or near the earth. For example, the shortest path between New York and Istanbul is given by:



As is displayed above, the toolbox also provides functions to plot the path over a globe.

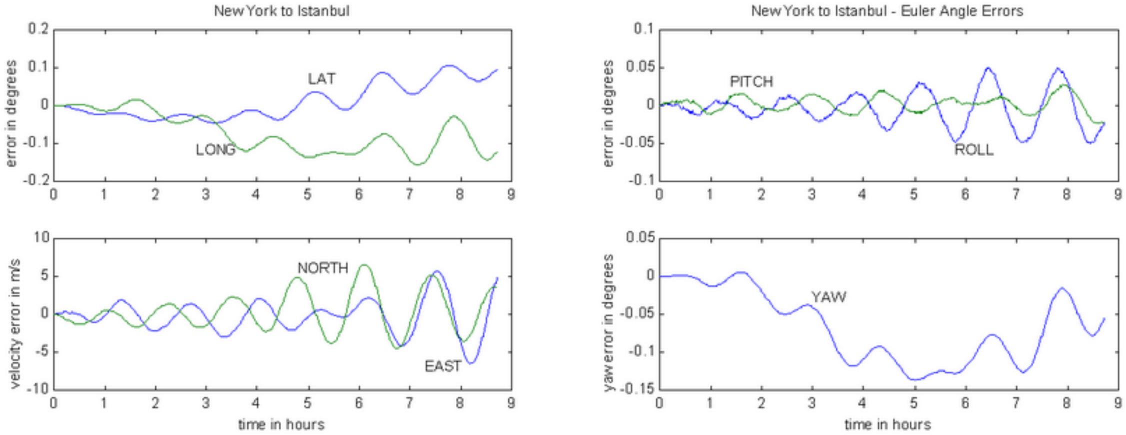
Great Circle Path INS Simulation with Sensor Errors

The INS toolbox supports INS simulations of great circle paths including errors. As an example, consider the path from New York to Istanbul. The ideal path is plotted over a globe here.

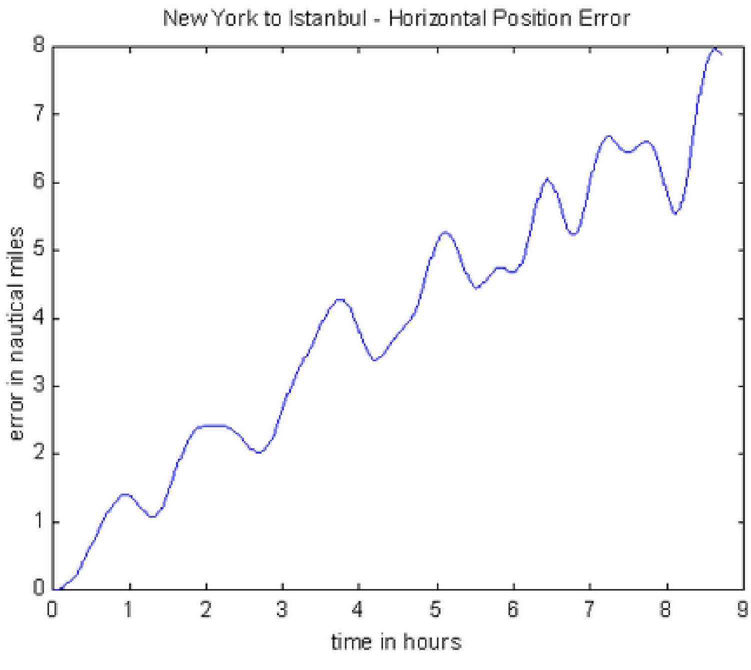
A demo program is provided with the toolbox to show how the toolbox functions may be used to simulate this scenario including sensor errors. The following sensor errors are simulated:

– 40 micro-g x-accel bias
– 50 micro-g y-accel bias
– 0.01 deg/hr x-gyro bias
– 0.015 deg/hr y-gyro bias
– 0.009 deg/root-hour x-gyro white noise standard deviation
– 0.005 deg/root-hour y-gyro white noise standard deviation

The position, velocity and attitude errors produced by the simulation are as follows:



On such a global scale, however, it is easier to think of position error in terms of nautical miles rather than degrees of arc. The toolbox provides for this with some convenient conversion programs. At each point along the path, the (simulated) inertially-derived position (lat/long) can be converted into local-level-tangent coordinate system with the true vehicle position as the origin. In this way the two components of horizontal position error are calculated and may be root-sum-squared. The results shows a navigation-grade INS with the typical nautical-mile-per-hour accuracy:

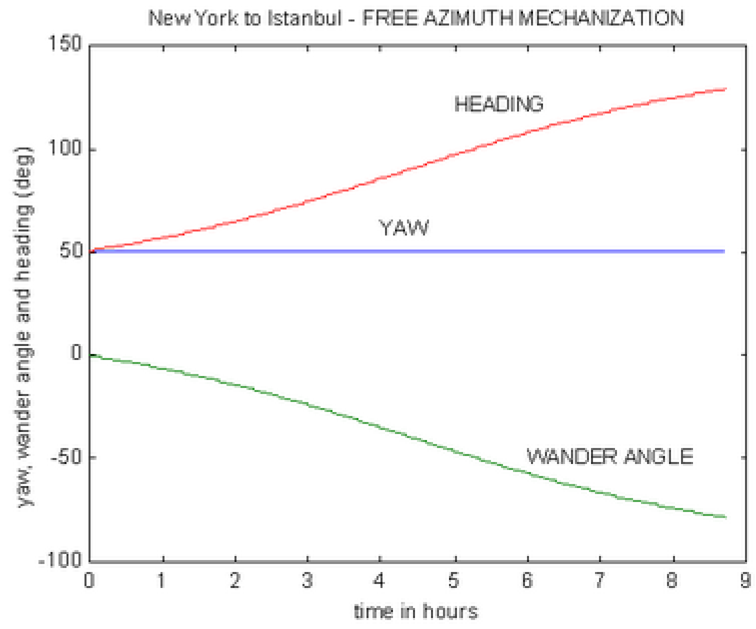


Wander Azimuth Mechanizations

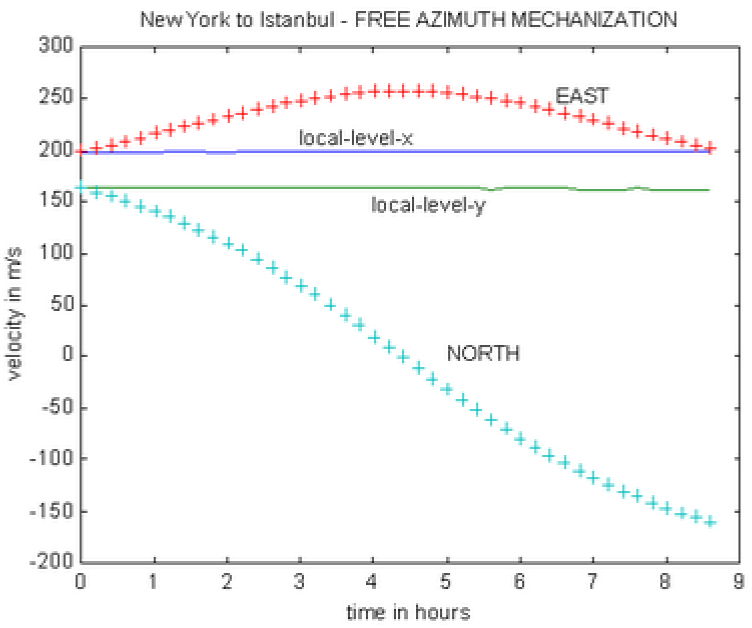
In addition to the north-slaved mechanization, the toolbox supports wander azimuth mechanizations including Free Azimuth, Foucault and Unipolar. Consider the following example simulations produced with the toolbox. In each case, a great circle path from New York to Istanbul was followed.

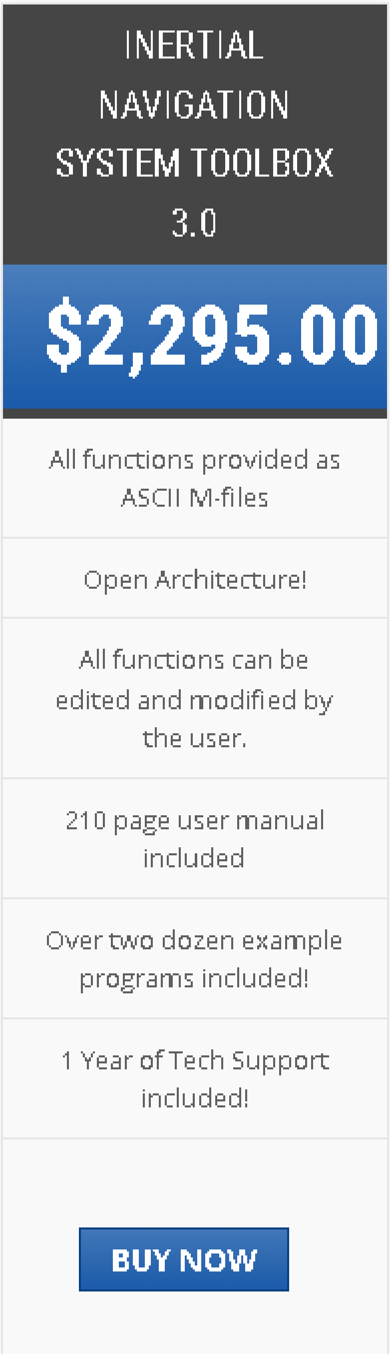
Free Azimuth Simulation

In the free azimuth case, the vertical component of craft rate is set to zero. As a result, the computed azimuth (yaw) remains constant. The actual heading is given by yaw-minus-wander-angle. Note that the wind is assumed to be zero thus the heading is also the aircraft course.



Since the local-level frame is NOT east-north-up (ENU), additional computation is required to determine east and north velocities:





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