

# Inertial Sensing & Navigation

3/9/2016

# GPS Noise

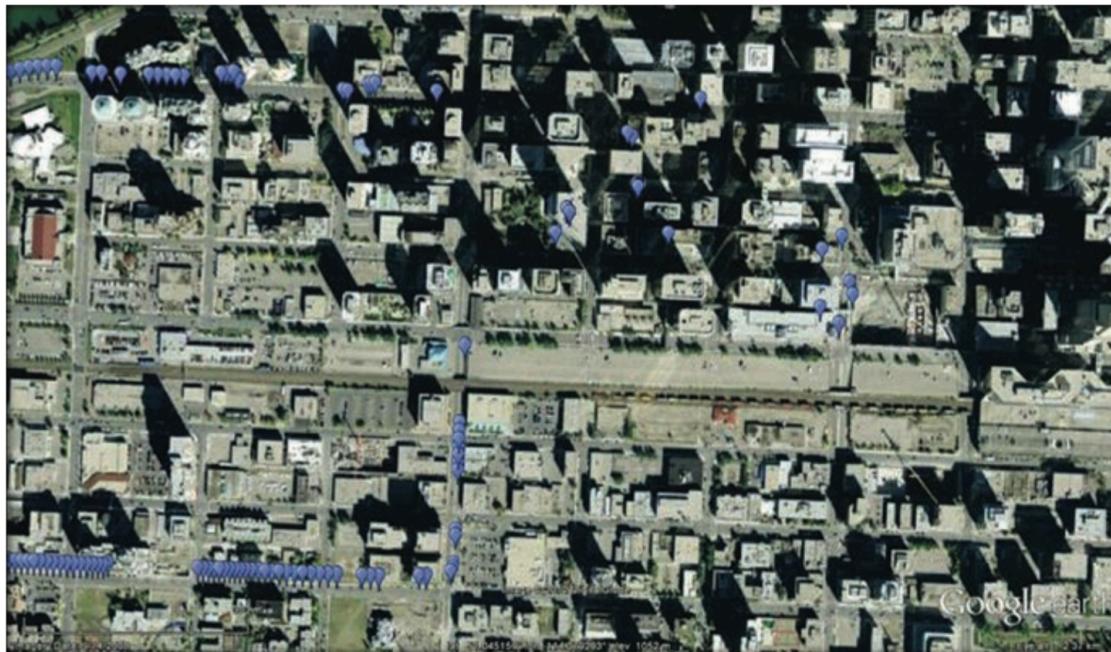


FIGURE 1 GNSS-only results in downtown Calgary

Source: [www.insidegnss.com](http://www.insidegnss.com)  
INS Face Off: MEMS versus FOGs

# Using INS to Avoid Noise



Source: [www.insidegnss.com](http://www.insidegnss.com)  
INS Face Off: MEMS versus FOGs

# Offroad INS-only Navigation

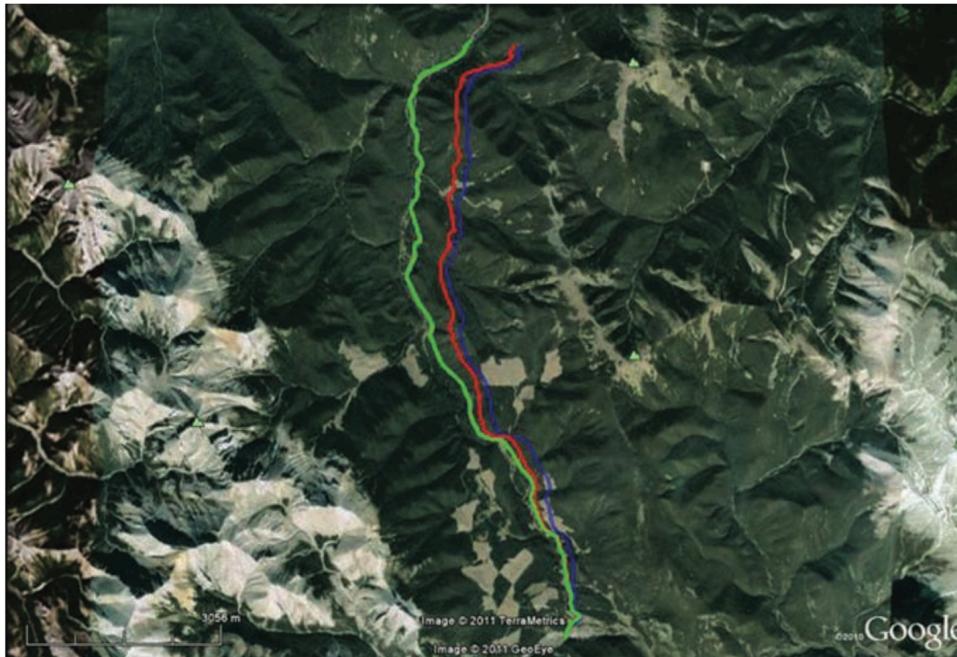
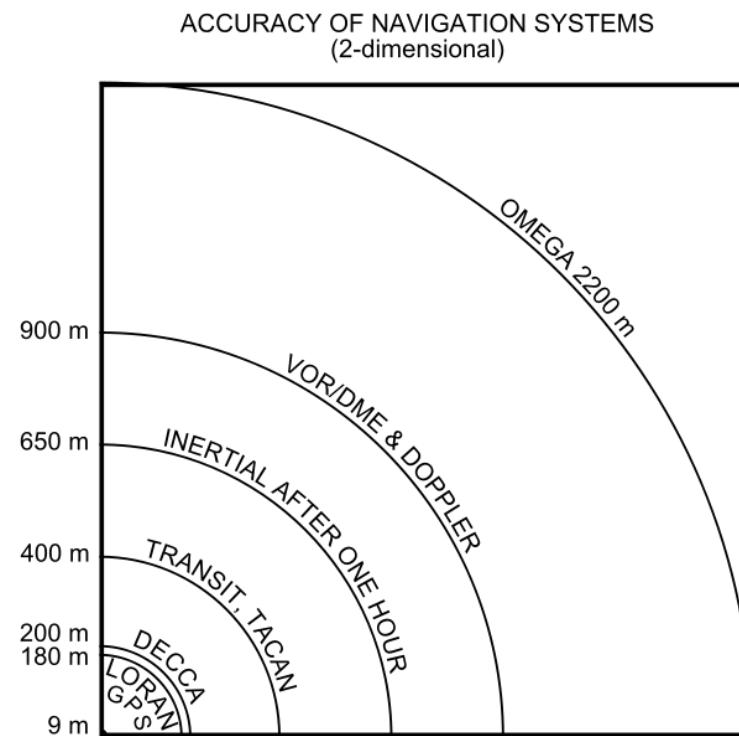


FIGURE 5 INS-only results off-road: reference in green, FOG in red, MEMS in blue

Source: [www.insidegnss.com](http://www.insidegnss.com)  
INS Face Off: MEMS versus FOGs

# INS Accuracy



Source: Wikipedia

# MEMS Accelerometer

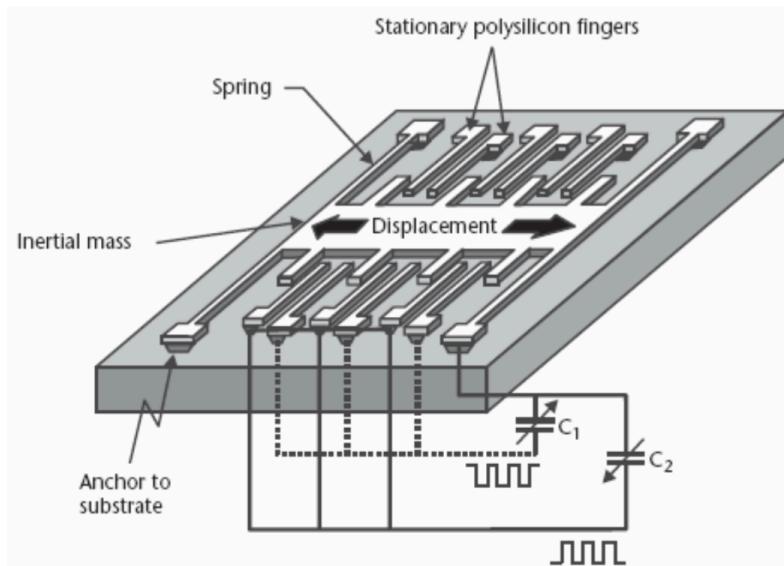


Figure 1.2 Illustration of the basic structure of the ADXL family of surface micromachined accelerometers

**Source:** Design and Analysis of  
a MEMS Comb Vibratory Gyroscope, Haifeng Dong MS Thesis

# Tuning-fork Gyroscope

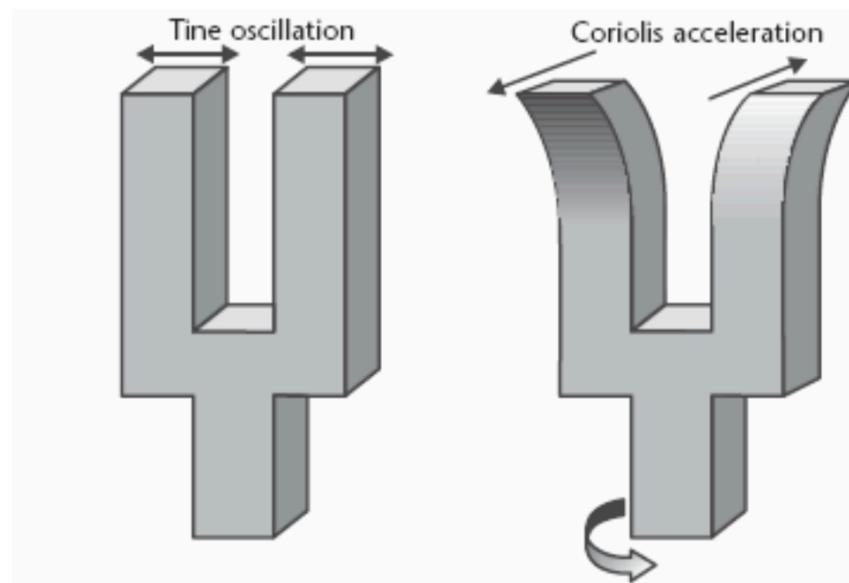


Figure 2.5 Tuning fork structure for angular-rate sensing

**Source:** Design and Analysis of  
a MEMS Comb Vibratory Gyroscope, Haifeng Dong MS Thesis

# MEMS Gyroscope

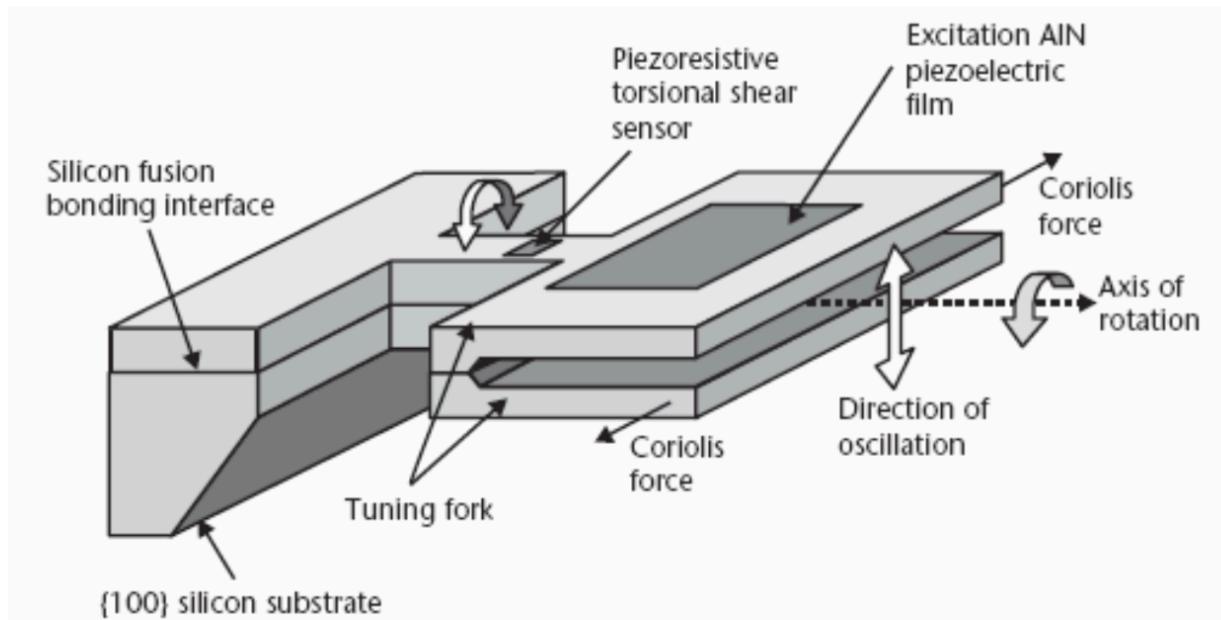
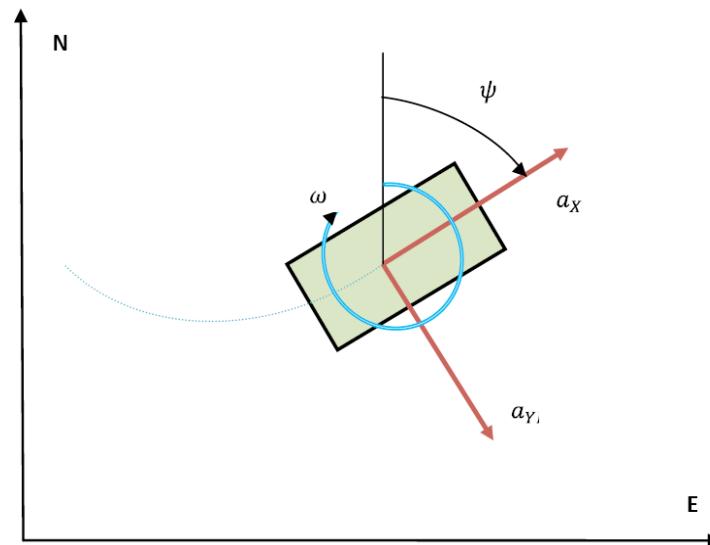


Figure 2.9 Angular-rate sensor from Daimler Benz

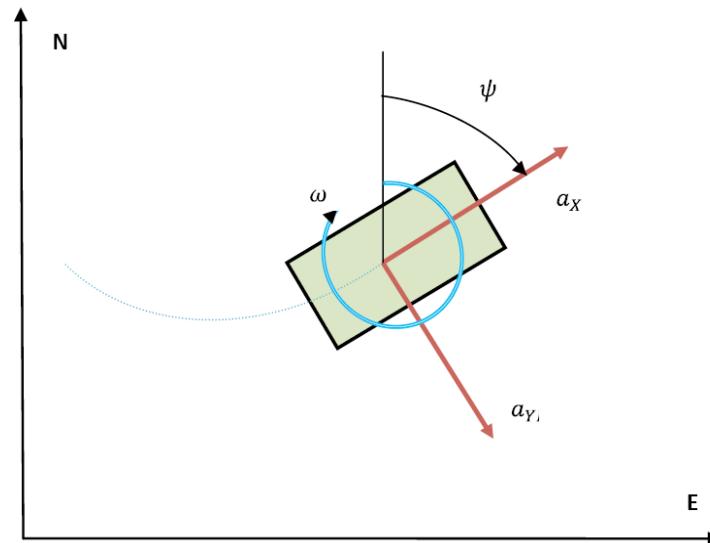
Source: Design and Analysis of  
a MEMS Comb Vibratory Gyroscope, Haifeng Dong MS Thesis

# Two-dimensional navigation for strapdown system



Source: Basic Principles of Inertial Navigation  
Seminar on inertial navigation systems  
Tampere University of Technology

# Two-dimensional navigation for strapdown system



Source: Basic Principles of Inertial Navigation  
Seminar on inertial navigation systems  
Tampere University of Technology

$$\begin{bmatrix} a_N \\ a_E \end{bmatrix} = \begin{bmatrix} \cos\psi & -\sin\psi \\ \sin\psi & \cos\psi \end{bmatrix} \begin{bmatrix} a_X \\ a_Y \end{bmatrix}$$

## Equations for 2D Strap-Down INS

$$\begin{bmatrix} a_N \\ a_E \end{bmatrix} = \begin{bmatrix} \cos\psi & -\sin\psi \\ \sin\psi & \cos\psi \end{bmatrix} \begin{bmatrix} a_X \\ a_Y \end{bmatrix}$$

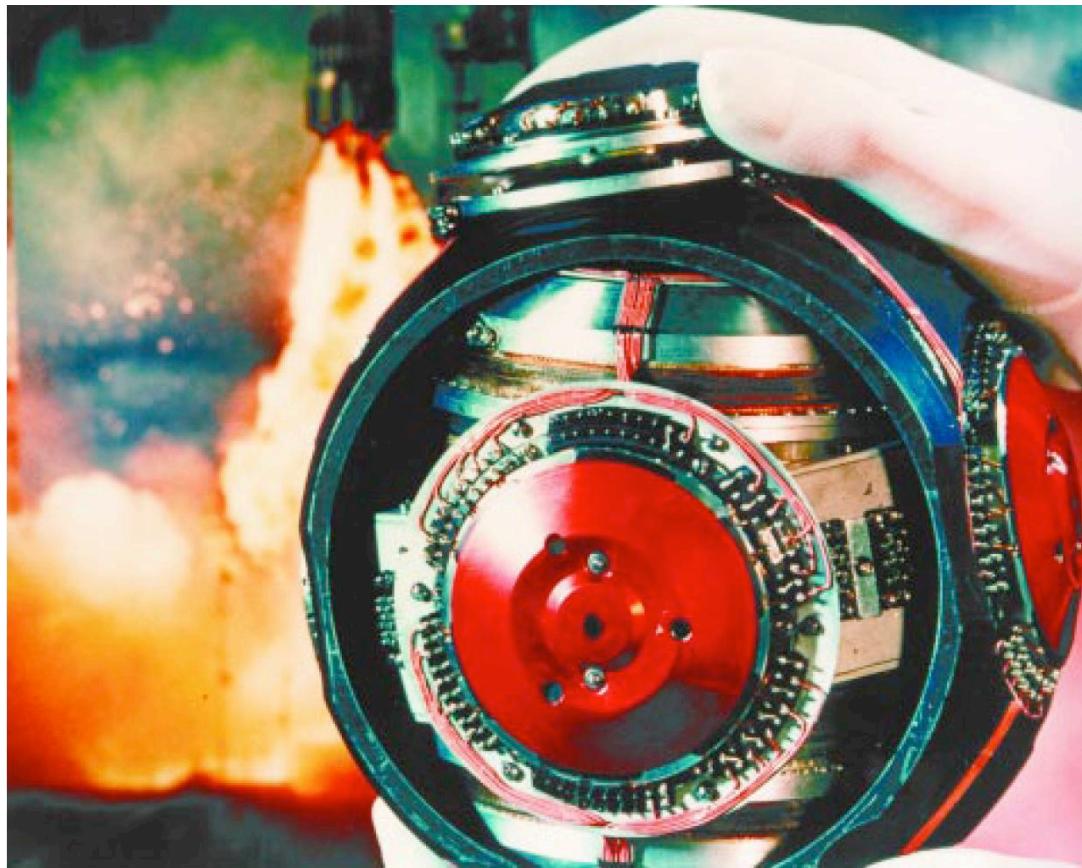
$$V_N(t) = V_N(t_0) + \int_{t_0}^t a_N(t) dt$$

$$V_E(t) = V_E(t_0) + \int_{t_0}^t a_E(t) dt$$

$$X_N(t) = X_N(t_0) + \int_{t_0}^t V_N(t) dt$$

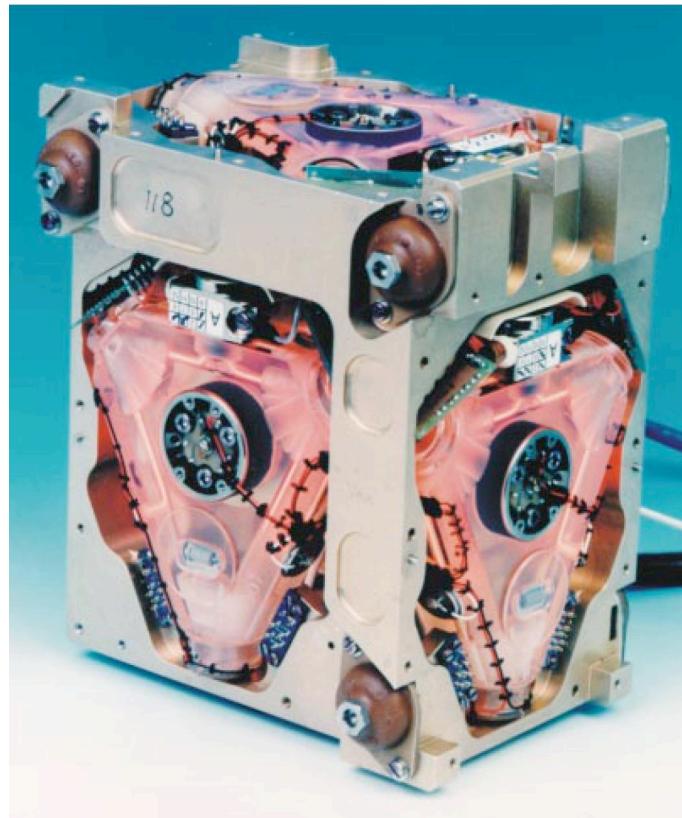
$$X_E(t) = X_E(t_0) + \int_{t_0}^t V_E(t) dt$$

# Gimbaled INS example



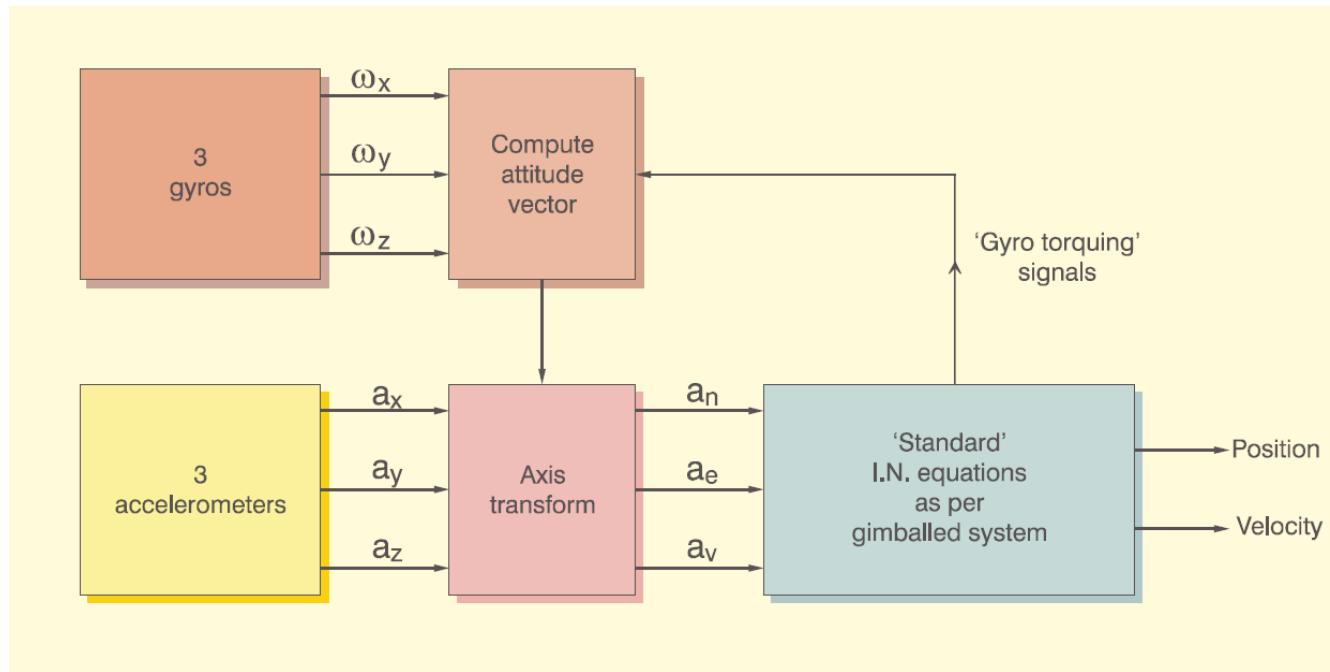
Source: Basic Principles of Inertial Navigation  
Seminar on inertial navigation systems  
Tampere University of Technology

# RLG instrument cluster (Marconi FIN3110 strapdown INS)



Source: Basic Principles of Inertial Navigation  
Seminar on inertial navigation systems  
Tampere University of Technology

# Strapdown inertial navigation unit block diagram

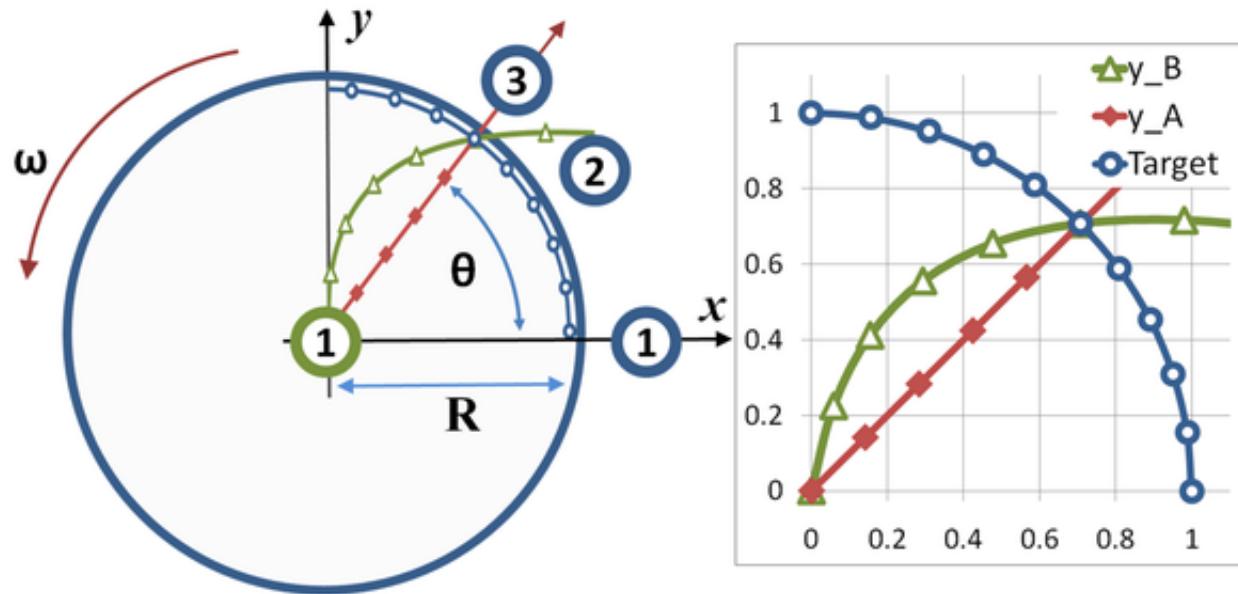


Source: Basic Principles of Inertial Navigation

Seminar on inertial navigation systems

Tampere University of Technology

# Coriolis Effect



Source: Wikipedia



- [https://www.youtube.com/watch?v=\\_36MiCUS1ro](https://www.youtube.com/watch?v=_36MiCUS1ro)

# Sources of Noise

Error Type	Description	Result of Integration
Bias	A constant bias $\epsilon$	A steadily growing angular error $\theta(t) = \epsilon \cdot t$
White Noise	White noise with some standard deviation $\sigma$	An angle random walk, whose standard deviation $\sigma_\theta(t) = \sigma \cdot \sqrt{\delta t \cdot t}$ grows with the square root of time
Temperature Effects	Temperature dependent residual bias	Any residual bias is integrated into the orientation, causing an orientation error which grows linearly with time
Calibration	Deterministic errors in scale factors, alignments and gyro linearities	Orientation drift proportional to the rate and duration of motion
Bias Instability	Bias fluctuations, usually modelled as a bias random walk	A second-order random walk

Table 2: A Summary of Gyro Error Sources.

Source: An introduction to inertial navigation, Oliver J. Woodman, UCAM-CL-TR-696