

# Introduction to Inertial Sensor and System Testing

Marius Gheorghe, PhD  
 Chief Engineer, Systems Solutions  
 Ideal Aeromsmith, Inc.  
 Phoenix, AZ, USA  
 mgheorghe@idealaero.com

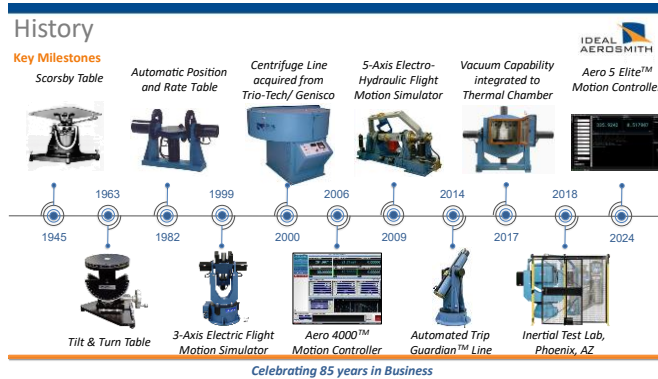
**Abstract**—The presentation aims to present the audience aspects related to the testing of inertial MEMS sensors and systems. A broad range of topics include an introduction to Ideal Aeromsmith Inc., common MEMS inertial sensors and systems, testing techniques, and Fehlerkultur.

## I. INTRODUCTION TO IDEAL AEROSMITH INC.

I will briefly introduce my employer, Ideal Aeromsmith, Inc., a premier manufacturer of inertial test equipment and provider of turnkey test solutions.

I will present in general lines the type of equipment, projects, and other offerings related to inertial MEMS sensors and systems.

Sample slides are included below:



## II. MEMS INERTIAL SENSORS AND SYSTEMS

I will introduce the three main categories of MEMS inertial sensors and systems.

### A. Accelerometers

I will present the main concepts behind MEMS accelerometers.

### B. Gyroscopes (Gyros)

I will present the main concepts behind MEMS gyros.

### C. Inertial Measurement Units (IMU)

I will present the main concepts behind MEMS IMUs.

Sample slides are included below:

#### Chapter 1- Introduction



#### Chapter 1- Introduction

##### Inertial Sensors – Main Types



##### Accelerometers:

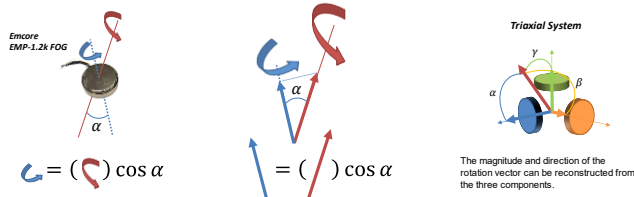
- Provide acceleration (also referred to as *specific force*) readings in the sensed axis/axes.
- Acceleration readings typically in  $m/s^2$  or  $g$  ( $1 g \approx 9.8 m/s^2$ ), but also in  $ft/s^2$ .
- Velocity change readings ( $\Delta V$ ) typically in  $m/s$ , but also in  $ft/s$ .

##### Gyroscopes:

- Provide rotation readings in the sensed axis/axes.
- Rate readings typically in  $^\circ/s$  or  $rad/s$ .
- Angle change readings ( $\Delta\theta$ ) typically in degrees or radians.

## Chapter 1- Introduction

Inertial Sensors – Sensor Cosine Response



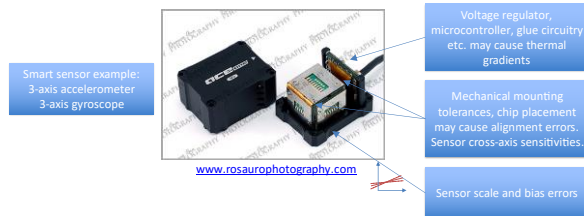
### III. RATIONALE FOR CALIBRATION AND TESTING

I will present the rationale for the calibration and testing of MEMS inertial sensors and systems, highlighting the typical error types. I will also introduce the linear error models.

Sample slides are shown below:

## Chapter 4- Calibration Topics

Motivation



## Chapter 3- Error & Correction Models

3-Axis Error Model – Equations



$$\begin{aligned} a_{xraw} &= S_x a_{xstim} + m_{xy} a_{ystim} + m_{xz} a_{zstim} + b_x \\ a_{yraw} &= S_y a_{ystim} + m_{yx} a_{xstim} + m_{yz} a_{zstim} + b_y \\ a_{zraw} &= S_z a_{zstim} + m_{zy} a_{ystim} + m_{zx} a_{xstim} + b_z \end{aligned}$$

$$a_{raw} = M a_{stim} + b$$

### IV. ACCELEROMETER CALIBRATION AND TEST PROFILES

I will present the typical calibration and test profiles used for MEMS accelerometers. I will cover the *tumble*, *centrifugal*, and *vibration* profiles.

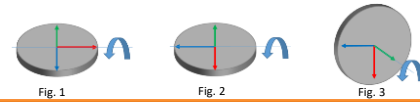
Sample slides are shown below:

## Chapter 4- Calibration Topics

Typical Accelerometer Calibration Profiles



- Set tabletop position by rotating around outer axis every 45° (Fig. 1).
- Rotate tabletop by 90°, then position by rotating around outer axis every 45° (Fig. 2).
- Rotate outer axis by 90°, then set tabletop position by rotating around inner axis every 45° (Fig. 3).
- Total of 24 independent positions (> 12 minimum required).
- Alternate test profiles are possible.

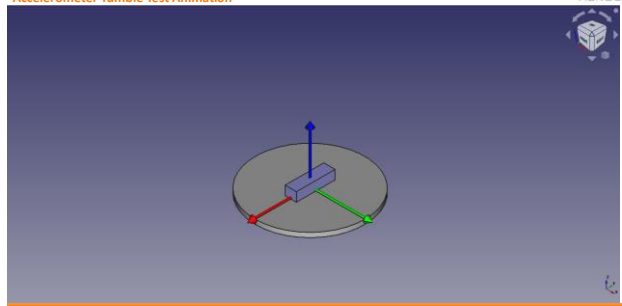


skip forward

6

## Chapter 4- Calibration Topics

Accelerometer Tumble Test Animation



7

### V. GYRO CALIBRATION AND TEST PROFILES

I will present the typical calibration and test profiles used for MEMS gyros. I will cover the *comb*, *canted*, and *g-sensitivity* profiles.

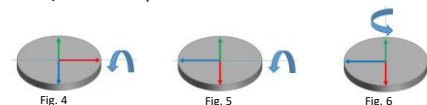
Sample slides are shown below:

## Chapter 4- Calibration Topics

Typical Gyroscope Calibration Profiles



- Rotate outer axis at a minimum of 2 positive and 2 negative rates as shown in Fig. 4.
- Same as above, but with inner axis positioned as shown in Fig. 5.
- Rotate inner axis at the same rates (see Fig. 6).
- Alternate test profiles are possible.



skip forward

8

### VI. IMU CALIBRATION AND TEST PROFILES

Will briefly summarize the specifics of the IMU (i.e. system) versus accel and gyro (sensors) calibration and testing.

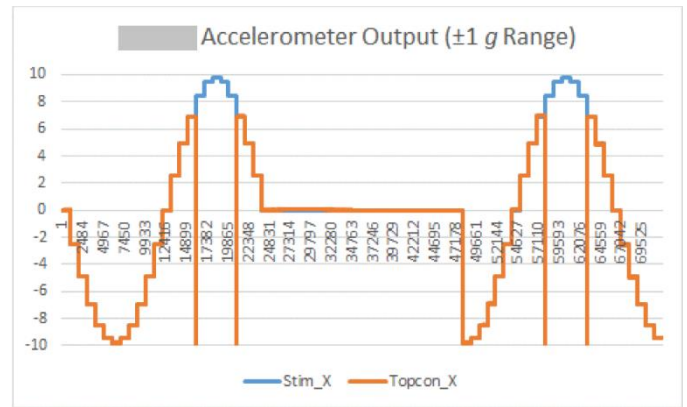
Sample slides are shown below:

## Chapter 4- Calibration Topics

UUT Noise Considerations



- ❑ Need to acquire many samples at each position or rate to help reduce the effect of the UUT noise.
- ❑ On limited outer axis rotation tables, may need to perform seesaw motions in order to acquire enough data points while the outer axis is at rate.
- ❑ Number of samples or interval of time needed for data acquisition to effectively eliminate noise can be determined through Allen variance studies.



## VII. THERMAL PROFILES

I will present the thermal dependence of various error model coefficients, thermal profiles and modeling.

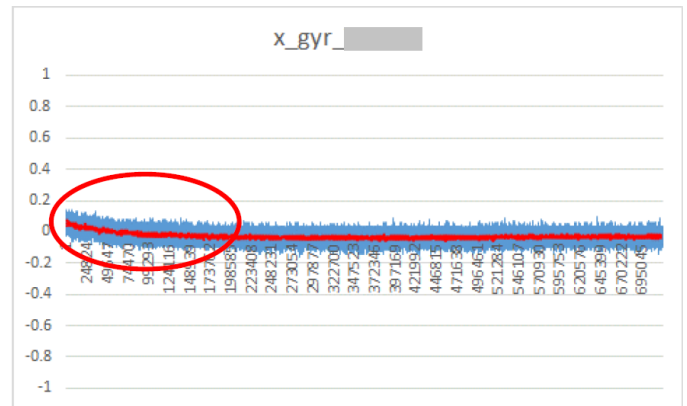
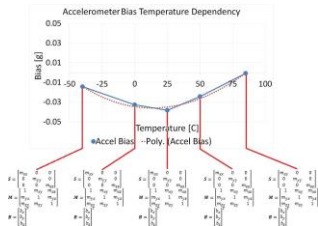
Sample slides are shown below:

### Chapter 4- Calibration Topics

Temperature Considerations 1/5



- ❑ Each of the correction coefficients may vary with the temperature:



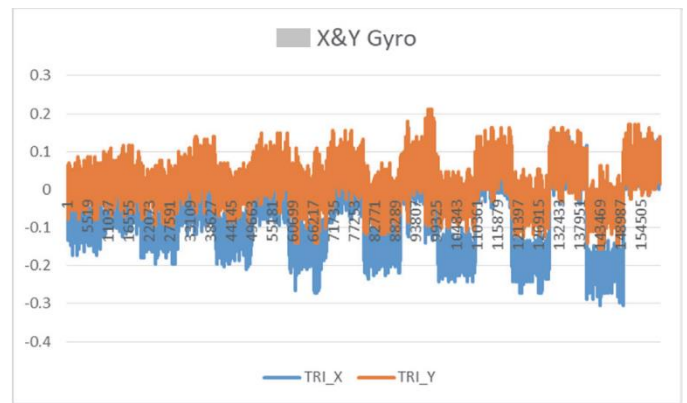
### Chapter 4- Calibration Topics

Temperature Considerations 2/5



- ❑ To compensate for their variation, complete calibrations are performed at various temperatures and then the temperature variation of each calibration parameter is modeled.
- ❑ Temperature models are typically performed with 3<sup>rd</sup> order polynomials, which requires the parameter values at a minimum of 4 different temperatures<sup>1</sup>.

<sup>1</sup>  $a_3x^3 + a_2x^2 + a_1x + a_0 \rightarrow$  model parameters:  $a_3, a_2, a_1, a_0 \rightarrow$  require minimum four equations



## IX. QUESTIONS AND ANSWERS

The attendees will have the opportunity to ask questions during the last 10 minutes of the presentation.

### REFERENCES

References will be presented on the last slide(s) of the presentation using IEEE-style citations.

## VIII. FEHLERKULTUR (CULTURE OF LEARNING FROM FAILURES)

I will present a number of interesting cases from the vast experience accumulated at the Inertial Test Laboratory (ITL) located at Ideal Aeromsmith's Phoenix facility.

Almost every project executed at the ITL discovered unexpected phenomena, deviations from the intended behavior, or other types of anomalies.

Sample graphs showing anomalies are shown below: