Metrology

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Metrology Requirements

- Position accuracy to 5 mm
- Attitude accuracy to 2.5°
- Refresh Rate of 50 Hz
Metrology Design

- Two independent systems
  - Infrared/Ultrasound (IR/US) GPS-like ranging system
  - Inertial navigation system (INS)
- Independent systems mitigate risk
- Systems augment each other
  - Inertial navigation system operable at 50Hz
  - IR/US system to provide initial position, update INS
  - INS provides position/attitude guess for IR/US calculations
## Metrology INS

- **INS measures:**
  - Angular Velocity
  - Acceleration

- **Integrates to provide:**
  - Velocity
  - Position
  - Attitude

- **INS is sampled by controller at 50 Hz**

- **For flight metrology:**
  - Kalman filter will be used in integrating IR/US position/attitude estimate with INS state estimate
Metrology INS Components

- Onboard Components
  - 1 Crossbow 3-axis accelerometer
    - Provides linear acceleration in 3 principal axes
  - 3 CFX single-axis gyros
    - Provide rotation rate around 3 principal axes
  - Tattletale processor

<table>
<thead>
<tr>
<th>Component</th>
<th>Vendor</th>
<th>Unit Mass (g)</th>
<th>Unit Volume (cm³)</th>
<th>Voltage</th>
<th>Unit Power (W)</th>
<th>Resolution</th>
<th>Picture (not to scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-Axis Accelerometer</td>
<td>Crossbow</td>
<td>15</td>
<td>15.63</td>
<td>8 to 30 V</td>
<td>0.080</td>
<td>.5 mg</td>
<td></td>
</tr>
<tr>
<td>Single-Axis Gyro</td>
<td>CFX</td>
<td>35</td>
<td>23.44</td>
<td>8 to 24 V</td>
<td>0.240</td>
<td>.025 deg/s</td>
<td></td>
</tr>
</tbody>
</table>
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Metrology INS Models

16.684 CDIO CDR Presentation

Objective
Motivation
Systems
Sub-systems
  - Structures
  - Propulsion
    - Metrology
  - Power
  - Avionics
  - Comm
  - Software
  - Systems
Program Plan

Summary

**Yaw error due to Gyro RMS noise**

**Position error due to Gyro RMS noise and Accelerometer RMS noise**

![Graphs showing yaw and position error over time](image_url)
INS Prototype Test Results

- CFX gyros validated using rate table
  - 16.62x setup used to evaluate gyro performance

- Accelerometer validated using manufacturer’s software
  - Crossbow software used to evaluated 3-axis accelerometer performance
Metrology IR/US System

- IR/Ultrasound ranging
  - 4 IR/US transmitter boxes at known locations in KC-135 or shuttle middeck
  - 8 IR/US receiver pairs on triangular panels of each satellite
  - Receivers measure time difference between arrivals of pulses
  - IR arrival instantaneous, range between emitters and receivers is difference times speed of sound

- Modified 3-D Newton’s method uses ranges, calculates position and attitude
Metrology IR/US Components

- Onboard components
  - 8 US receivers
  - 8 IR receivers
  - Tattletale processor (discussed by Avionics)

<table>
<thead>
<tr>
<th>Component</th>
<th>Vendor</th>
<th>Unit Mass (g)</th>
<th>Unit Volume (cm³)</th>
<th>Voltage Required</th>
<th>Unit Power (W)</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 kHz Ultrasonic Transceivers</td>
<td>MuRata Electronics</td>
<td>2.39</td>
<td>2.5</td>
<td>5</td>
<td>~0</td>
<td>![Image](40kHz Transceiver.png)</td>
</tr>
<tr>
<td>IR Receiver (880 nm)</td>
<td>Vishay Telefunken</td>
<td>.226</td>
<td>0.2</td>
<td>5</td>
<td>~0</td>
<td>![Image](IR Receiver.png)</td>
</tr>
<tr>
<td>IR Emitter (880 nm)</td>
<td>Photonic Detectors</td>
<td>~0</td>
<td>~0</td>
<td>5</td>
<td>~0</td>
<td>![Image](IR Emitter.png)</td>
</tr>
</tbody>
</table>

- Transmitter box components
  - US transmitter
  - IR transmitter
  - IR receiver
  - Tattletale processor
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**SPHERES IR/US Prototype Test Results**

- **1-D system tests**
  - Required linear accuracy achievable
  - Multiple components tested, best performing components selected
  - Conditioning circuits optimized

- **2-D system tests**
  - Developed position and attitude code
  - Validated Newton’s Method equations
  - Developed stand-alone synchronized transmitters

- **Systems level tests**
  - Propulsion jet noise affects US receivers
  - Propulsion electronic noise affects unshielded metrology components
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IR/US Prototype Results

- Built stand-alone 2D testbed
  - Finalized IR/US conditioning circuits
  -Verified 2D Newton’s method equations
  - Prototyped transmitter box design
Comparison with Requirements

- Position accuracy 2 cm  
  - 5 mm current requirement

- Attitude accuracy ±5°  
  - 2.5° current requirement

- INS meets 50 Hz sampling requirement
**Design Modifications for Flight**

- **Inertial system**
  - Develop better integration method
  - Use error estimation to improve accuracy of metrology system
  - Quantify gyro drift using rate table

- **IR/US system**
  - Finalize design for transmitter boxes
  - Develop equations to calculate 3D position and attitude
  - Develop transmitter box auto-positioning system (BAPS)

- **Integrate IR/US metrology systems and Inertial Navigation System**

- **Electrically shield all metrology components and connectors**