746th Test Squadron

Innovate, Execute, Excel

Testing the Latest Embedded GPS/INS Hybrid Navigation System for the F-16 Fighting Falcon

13 March 2007

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746 Test Squadron
Holloman AFB NM

Integrity - Service - Excellence - Agility
UNCLASSIFIED
Overview

- F-16 LN-260 EGI Test Item
- Approach and Test Methodology
- Test Capabilities Available at 46 Test Group
- LN-260 Overall Test Objectives
- Sequence Selected for Test Beds & Assets
- Truth Reference System to be used
- Summary / Lessons Learned / Conclusions
- Questions
F-16 Fighting Falcon

Integrated INS & GPS Navigation System for USAF and European Participating AF (EPAF)

- Integrated Navigation system provides
  - Attitude
  - Navigation (PVT)
    - Position
    - Velocity
    - Time
Current Navigation System

- Separate GPS and INS units

INS: Ring Laser Gyro
Inertial Navigator

GPS: 5 Channel PPS
Satellite Receiver

Kalman Filter

Blended GPS/INS PVT Solution

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F-16 Hybrid Nav System

- LN-260 NG Aircraft Navigation and Attitude
  - Inertial Navigation System (INS) < .8 nmi/hr RER
    - New Fiber Optic Gyros
  - GPS: RC GEM-VI, 24 channel L1 & L2 receiver
    - Single Unit; smaller size, weight, cost, power use
- Embedded GPS in INS (EGI), with Kalman Filter

- Provides 3 separate solutions:
  - INS only, GPS only, Blended
    - ‘Tightly coupled’
- Same Performance?
- Effective and Suitable?
  - Requires T&E
Notional Test Approach

DYNAMICS: Gs & Rates

SENSORS:
- Accelerometers ~ Gs
- Gyros ~ Rotational Rates
- (GPS Receiver ~ Noise/Signal)

Test Phases
Test Bed Costs

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Test Approach

Crawl - Walk - Run

Discover and correct issues early at a lower cost

Mature the system design

• Methodically verify proper functionality of navigation unit
  – Physical and functional checkouts
  – Precision three axis table attitude and rotations

• Establish baseline performance
  – Benign, controlled, repeatable environment
  – Recheck as appropriate
Test Approach (cont)

• Performance and Characterization

  – Gradually increase stresses on sensors and system to the specification limits while measuring performance in realistic profiles that are controlled and repeatable

  – The greater the dynamics and signal stress the more exposed existing problems become

  – Use state-of-the-art Truth Reference System
Test Location: 46 Test Group
Holloman AFB NM

- State-of-the-art Test Capabilities
- 746 TS; Central Inertial & GPS Guidance Test Facility (CIGTF)
46th TG Test Capabilities

- 5 Test Squadrons within 46th Test Group
  - 586 FLTS: Flight Test Squadron
  - 746 TS: INS & GPS Guidance Test Squadron (CIGTF)
  - 781 TS: National RCS Test Facility (NRTF)
  - 846 TS: Holloman High Speed Test Track
  - Det 1: White Sands Missile Range Test Agent

- 746 TS / CIGTF: Has complete range of GPS & INS Navigation and Guidance test capabilities
  - Satellite Ref Station (SRS)
  - Mobile SRS (MRS)
Available Live Nav Test Beds

Dynamic Range Vehicles; Track, Van, Helo, C-12, Fighters

High Speed Precision Test Track

Land Navigation Vehicles

Helicopter  C-12  T-38  F-16, F15
Inertial and GPS Lab Facilities

Advanced Inertial Test Lab    Seismically Stable Table      M&S Navigation T&E Lab

Precision 3 Axis tables with Temperature Chamber

120” Precision Centrifuge

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Test Objectives for LN-260 EGI

• Verify the F-16 LN-260 EGI performance complies with the published specifications and characterize significant aspects without specification

• Functional
  – Check physical, power and data properties
  – Demonstrate operation of interfaces and EGI modes
  – Baseline navigation outputs

• Performance
  – Evaluate the navigation performance under realistic operational and environmental conditions

• Characterization
  – Characterize calibration errors

• Areas of concern include effect of temperature, G and vibration on navigation performance
Test Bed Progression

- Bench top physical and functional checks
- Precision 3 Axis table position/rotations
  - 24 position tests at temperature variations
  - Inertial sensor calibrations
- Modeling and Simulation; NavTEL
- Van land navigation vehicle, low dynamics
- C-12 cargo aircraft, low-med dynamics
- Precision 3 Axis inertial calibration recheck
- T-38 Fighter aircraft, med-high dynamics
- Environmental: altitude, vibration, high G

Low Cost  Preparatory
Med Cost  Comprehensive
High Cost  Controlled environment
Increased risk
3 Axis Rate Table 53Y

**Precision 3 Axis: Position, Rotation, Temperature Tests**

- Payload (200 lb)
- Accuracy (1 arcsec)
- Gimbal Rates ($\pm 750$ deg/sec)
- Chamber (-55 to +85 deg C)

- Functional Alignment and Navigation
- INS Calibration Validation
  -- 24 Positions (1g Environment)
  -- Rotation Rates (20 deg/sec)
- Calibration / sensor baselines
Modeling & Simulation

Navigation T&E Laboratory (NavTEL)
- Hardware-in-the-Loop Design
- Trajectories (Real & Simulated)
- Models: Sensor & Aiding, w/ Realistic Errors
- GPS Simulators (Spirent 4760 / 7700)
- EGI Simulator (CAST) Hybrid, > Fidelity
- Select Parameter Controlled On the Fly
- Interference Signal Generators (Jammers)
- Wave Front Simulator (Multi-Element Antenna Test)

- Controlled Signal Injection
  - INS & GPS profiles
  - Models: Baro, Doppler, +
  - Special Navigation Ops
  - Jamming (broad scope)
  - RAIM Integrity Monitoring
  - SAASM Security Functions
CRPA Wave Front Testing

- Null Steering Antenna Tests
- Embedded Jammer Approach
- Jamming; up to 16 Sources
- Precise and Repeatable Tests
- Coherent Arrival Vectors, GPS and Jamming
- Controlled Signal Location, Timing & Phase

Coherent Wave Front Sim for GPS and Jamming signals

3 Jammer example: 30, 60, 270

Predicted Model
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Measured Results

Controlled Reception Pattern Antenna
Operational - Live Performance

Low Dynamic Test
- Land Navigation Vehicle
  - Velocity (26.8 m/sec)
  - Acceleration (1g)
  - Navigation Modes
  - GPS Jamming
  - Precision Reference

Medium Dynamic Test
- Cargo Aircraft (C-12J)
  - Velocity (140-250 kts)
  - Acceleration (2.5g)
  - Navigation Modes
  - GPS Jamming
  - Precision Reference

High Dynamic Test
- Hi Performance (T-38)
  - Velocity (Mach 1.1)
  - Acceleration (7.2g)
  - Air to Grnd scenarios
  - Air to Air scenarios
  - Precision Reference

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Field Jamming Assets

• GPS Interference; Performance under signal stress

Jamming Vans

High Gain Antenna

WSMR Test Range

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GPS Signal Jamming Stress

Jamming Strength
- High
- Med
- Low

NavTEL
- Simulated dynamic or static profile

Van, C-12
- Live Signal and dynamic profile

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Environmental Lab Capabilities

- Test specification requirements not reached on previous test beds

Altitude / Temp Chamber
- Payload Navigating
- Pressure Altitude 80K' +
  - 50-60K’ planned
- Temp to match altitude
  -100 deg to +350 deg
- Humidity 5% – 95%

Vibration test beds
- Frequency/G controlled
- F-16 vibration profile
- M-60 Gatling gun
- Up to 1750 lbs force
- 2-2000 Hz (50#, 70g)
- 1 inch travel

Centrifuge 120” Radius
- Payload (100 lb)
- Accuracy (1 ppm)
- Acceleration (0.5 to 50 g)
- 13.5 g planned
- Test Item Fixture:
  - Fixed or
  - Counter- Rotating
Test Bed Gs and Rates

(Approximate)

Dynamics (g)

Rate

G

Rates
deg/s
CIGTF Reference System (CRS) - Pallets

Rack Mount

DAS

EGI

C-12J / Van

Standalone

( T-38 )

Fighter Inertial Navigation System (FINS)
Rack Mount (Development)
## CRS - Subsystem Configuration Accuracy

### RMS Position (m)

<table>
<thead>
<tr>
<th>[Subsystem]</th>
<th>Configuration</th>
<th>Horz</th>
<th>Vert</th>
<th>3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1] [2] GPS Code</td>
<td>2.00</td>
<td>2.25</td>
<td>3.25</td>
<td></td>
</tr>
<tr>
<td>[1] [2] DGPS Code&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1.25&lt;&gt;1.75</td>
<td>1.0&lt;&gt;1.75</td>
<td>1.5&lt;&gt;2.5</td>
<td></td>
</tr>
<tr>
<td>Carrier&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.30</td>
<td>0.20</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>[4] RRS / STARS</td>
<td>1.40 / 0.14</td>
<td>1.00 / 0.10</td>
<td>1.7 / 0.17</td>
<td></td>
</tr>
<tr>
<td>STS Absolute / Relative</td>
<td>0.071 / 0.0014</td>
<td>0.05 / 0.0010</td>
<td>0.087 / 0.0017</td>
<td></td>
</tr>
</tbody>
</table>

SRS Range Constraints: 1<sup>300-500nm</sup> 2<sup>50-100nm</sup> Differential GPS

### RMS Velocity (m/s)

<table>
<thead>
<tr>
<th>[Subsystem]</th>
<th>Configuration</th>
<th>East</th>
<th>North</th>
<th>Up</th>
<th>3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1] INS (EGI)</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>[3] INS (ESNU)</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.010</td>
<td></td>
</tr>
</tbody>
</table>

Attitude Accuracy: 20 arcsec (Roll, Pitch, Heading)
SUMMARY

• CRAWL
  – Benchtop physical and functional tests
  – 53Y 24 precision position, attitude and rotations
  – Baseline performance for inertial portion

• WALK
  – NavTEL Modeling & Simulation
  – Van 2D low dynamics, low rates
  – Baseline GPS, INS and Hybrid solutions

• RUN
  – C-12, 3D med dynamics, med rates
  – T-38, 3D high dynamics, high rates

• Environmental
  – Centrifuge; Altitude chamber; Vibration profiles
  – Higher risk and stress modes
Lessons Learned

- Often PM tendency is to streamline the T&E phases due to Cost and Schedule pressures.

- Testing **WILL** find unanticipated problems, guaranteed.

- A thorough and systematic government independent T&E approach will actually reduce ultimate cost and schedule by finding/correcting problems **early**
  - “Rely on Independent Government Test”
  - “Focus on Performance”

( Words of Gen Randolph, JNC 2004)
CONCLUSION

• Follow well planned graduated test approach that manages risk and finds and fixes problems early
• Avoid cutting plan to save time or $, which often increases Cost and Schedule.
• Thorough Benchtop and 3 Axis table tests are valuable in uncovering problems early, prior to van and flight testing
• Match tests to realistic environment as practicable
• Apply increased stress in a controlled fashion
• Place high risk tests at the end to reduce possible early schedule impacts due to system failure
Recap

- LN-260 EGI
- Wide range of test capabilities in house
- Benefits of selected order
  - “Crawl, Walk, Run”
  - Facilitates testers familiarity with test item
  - Establish Baseline performances
  - Comprehensive; identify & isolate problems early
  - Risk managed to reduce ‘re-fly’ schedule impact
  - Mature system design in most cost efficient method
  - Continuity with same team of experts throughout
All to support the Warfighter

Questions?

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Back Up Slides

- CIGTF Reference System Block Diagram
- CRPA Wave Front System Block Diagram
CIGTF Reference System Architecture

Reference Pallet Configuration (CRSP)

- FRPA/CRPA
- Spectrum Analyzer
- GPS Environment
- INS/GPS/BLD
  \( \Delta \omega, \Delta \theta \)
  Code, Carrier

DAS Data Acquisition System

- Altitude Encoder
- Display Real-Time
- Gravity DOV

EGI INS/GPS/BLD

GPS Receivers
Code / Carrier

ESNU INS Standalone

RRS STARS STS

Satellite Reference Station (SRS)

- GPS Receiver
  Code / Carrier

- BM Reference Survey

Pre-Process

Post-Process

Reference Trajectory

Loosely/Tightly Integrated System

Kalman Filter Smoother

Post-Mission Processing

Ground Transponders / Pseudolites / Track Space Time
Wave Front CRPA Simulation

7 x GSS7700 Dual RF

Modified SimGEN PC

Master Unit

GPIB

L1 (Jam)

L1,2 (Jam)

L1,1 (GPS)

L1,2 (Jam)

L1,1 (GPS)

L1,1 (GPS)

L1,2 (Jam)

L1,1 (GPS)

To Rx

Antenna Electronics Unit

Backup Slide

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