An Overview of Electromagnetic Effects (EME) for Aviation Safety and Security

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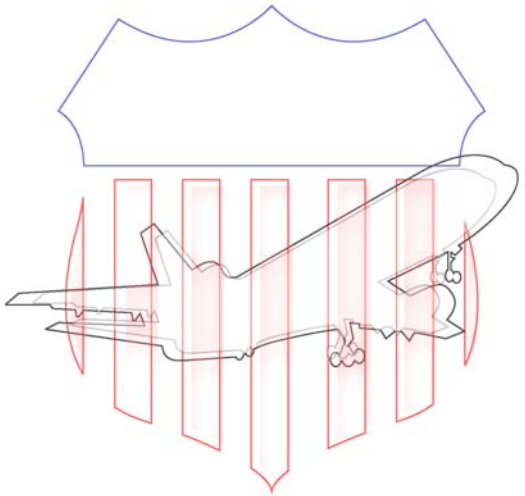
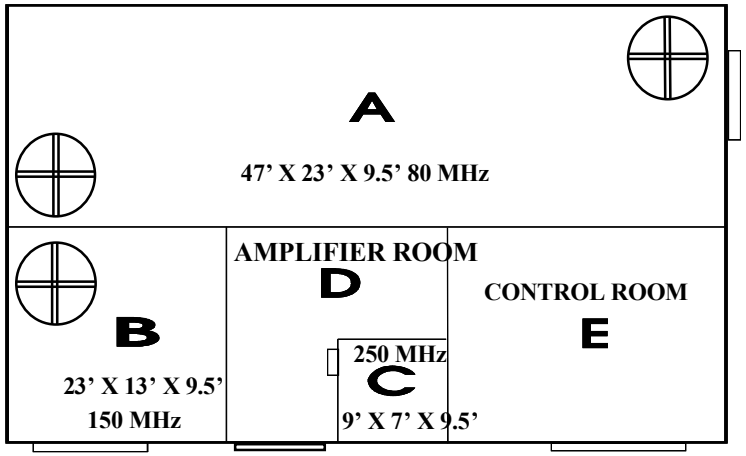
Background

- Since 1993, ERB has been conducting research & development work in EME for Aviation Safety
- Primary facility has been the High Intensity Radiated Fields (HIRF) Lab
- Since 9/11/2001, EME work has expanded to include elements of Aviation Security



HIRF Lab Facility

- HIRF Lab is located in Bldg. 1220, Room 144
- Facility was constructed in 1993 under the Fly-by-Light/Power By Wire Program
- Cost of facility: $450K
- HIRF Lab consists of 4 separate reverberation chambers
- Control room, amplifier room



HIRF Lab Equipment

- 120 dB shielded reverb chambers
- State of the art facility
- Performance/repeatablity characterized by NIST to within +/- 1 dB
- Currently have CoF to add 20’ access door to Chamber A
- 1250W amplifier, 100MHz – 1 GHz, 3,000 V/m field intensity
- Second amplifier, 10kHz – 250 MHz, 2,000 W CW, 4,000 W pulsed

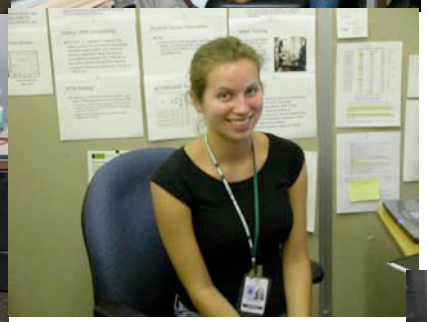
- 1.5kW amplifiers, 1 GHz – 18 GHz
- Lightning indirect effects test equipment (very few test sets worldwide: Boeing, Airbus)
- 2 Agilent E4407B portable spectrum analyzers (9 kHz – 26 GHz)
- Anritsu portable spectrum analyzer

HIRF Lab Test Capabilities

- Full DO-160D HIRF test capability
- MILSTD-461 test capability
- Lightning indirect effects test capability
- Radiated emissions
- Radiated susceptibility
- Impedance measurements

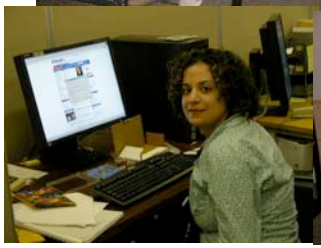
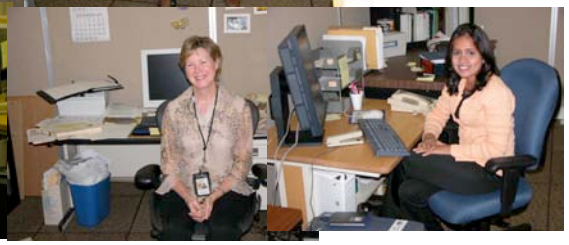
HIRF Lab Staff



- 5 Civil Service FTEs
- 3 Performance Based Contractors
- 3 GSRP students from ODU
- 1 LARSS summer student
- 1 ODU EE professor
- Reuben Williams, HIRF Lab Manager
- Truong Nguyen, Research Engineer
- Jay Ely, Research Engineer
- Sandra Koppen, Research Engineer
- John Beggs, AvSec EME Project Manager
- Teresa Salud, Research Engineer



- Genevieve Hankins, ODU graduate student
- Mennatoallah Youssef, ODU graduate student
- Madiha Jafri, ODU graduate student
- Dr. Linda Vahala, ODU EE professor
- Allen Freeman, LARSS UMD EE summer student
- Max Williams, Lab Technician
- Chace Hall, Computer Systems Administrator

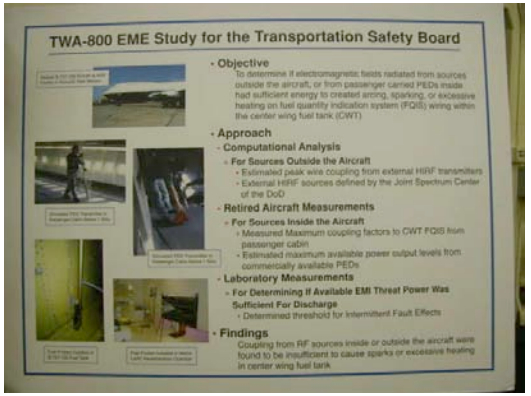
HIRF Lab Awards & Professional Activities

- 1997 NASA Group Achievement Award
- 2001 HJE Reid Award
- 2001 DASC Best Session Paper
- Madiha Jafri: Best Student Paper Award, 2004 IEEE International Symposium on Electromagnetic Compatibility
- Menna Youssef & Genny Hankins: 1st place in 2004 IEEE Hampton Roads Section Student Paper Contest, 3rd Place in 2004 IEEE Southeastcon Student Paper Contest
- IEEE Members, 1 IEEE Senior Member
- Paper reviews for IEEE Antennas & Propagation Society
- RTCA SC202 Committee participation (Portable Electronic Devices on airplanes)
- RTCA SC135 Committee to develop DO-160 HIRF certification standards
- SAE AE-2 Lightning Committee
- Applied Computational Electromagnetics Society Editorial Board
- Conference participation in IEEE Antennas & Propagation Society, Electromagnetic Compatibility Society, Digital Avionics Systems Conference

Aviation Safety EME

TWA Flight 800 EME Investigation

- **Objective was to determine if external RF transmitters or passenger carried PEDS could create a spark on FQIS to ignite fuel vapor in center wing fuel tank**
- **Sponsored by NTSB**
- **Three-level approach**
  - **Computational Analysis: RF field coupling inside A/C to FQIS from external sources**
  - **Retired A/C measurements: measurements of field levels due to internal sources (PEDs) on a retired A/C**
  - **Laboratory measurements: determine if EMI threat power was sufficient for discharge**
- **Work included a lab mock-up of FQIS**
- **Findings indicated EMI threat was insufficient to cause discharge**
- **Final NASA report received HJE Reid Award**



Aviation Safety EME

Interference Path Loss Measurements

- **Cooperative effort with United Airlines and Eagles Wings, Inc.**
- **United Airlines provided six B737-400 and four B747-400 aircraft and engineering support**
- **NASA provided:**
  - **Funding for EWI's participation**
  - **Two sets of instrumentation for concurrent measurements**
  - **Data acquisition software and support**
  - **Manpower, data analysis**
- **Measurements were taken during three 1-week trips to Southern California Aviation in Victorville, CA**
  - **Four B747-400: LOC/VOR, VHF-1 Comm, GS, TCAS-Top, GPS, Satcom**
  - **Six B737-200: LOC/VOR, VHF-1 Comm, GS, TCAS-Top, GPS**
- **IPL results were summarized and compared with other existing path loss data**

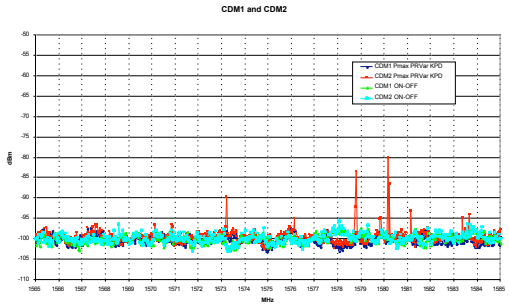
Aviation Safety EME

Portable Electronic Devices (Cell Phones)

- **Reimbursable FAA Interagency Agreement DFTA03-96-X-90001, Single Aircraft Accident Prevention Project (SAAP)**
- **Objective was to develop a radiated emission measurement process for cellular telephones and to provide a preliminary risk assessment of unintentional interference to aircraft radio receivers.**
- **Measurements included CDMA and GSM cellular technologies**
- **Consumer grade CDMA and GSM telephones were tested**
- **Findings indicated interference was unlikely due to CDMA and GSM telephones**

CDMA Telephones

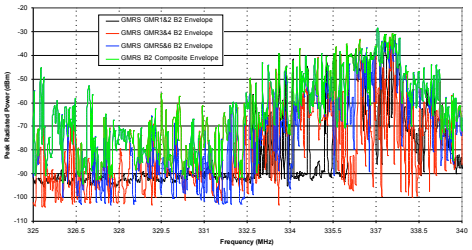
GSM Telephones



Aviation Safety EME

Portable Electronic Devices (Wireless LAN/NAV)

- **Reimbursable FAA Interagency Agreement DFTA03-96-X-90001 & SAAP**
- **Objective was to develop a radiated emission measurement process for WLAN devices, FRS/GMRS radios, conduct aircraft IPL measurements and to provide an interference risk assessment of these devices to aircraft radios and GPS.**
- **Measurements included IEEE 802.11a/b, Bluetooth and FRS/GMRS radio wireless technologies**
- **IPL measurements on six B737-200 and four B747-400 aircraft**
- **Consumer grade wireless devices were tested**
- **Findings indicated spurious emissions from certain wireless devices can be higher than DO-160D, Category M standards**
- **Interference safety margins can be positive or negative, and are based on IPL and interference threshold values**



802.11A

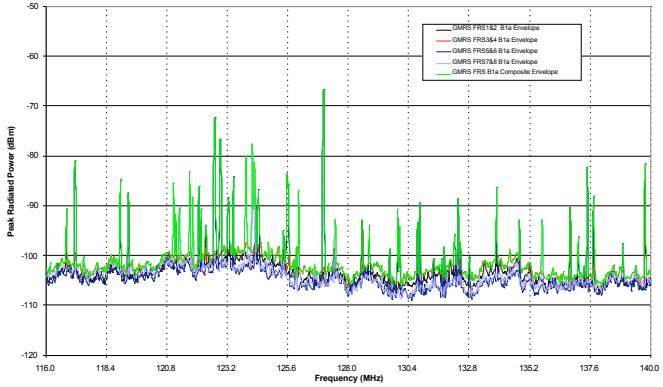
802.11B

Bluetooth

Aviation Safety EME

Portable Electronic Devices (Wireless LAN/VHF Com)

- **Reimbursable FAA Interagency Agreement DFTA03-96-X-90001 & SAAP**
- **Extend prior WLAN measurement & risk analysis process to VHF Com band**
- **Measurements included IEEE 802.11a/b, Bluetooth and FRS/GMRS radio wireless technologies**
- **Prior IPL measurements on six B737-200 and four B747-400 aircraft were used in analysis**
- **Consumer grade wireless devices were tested**
- **Similar findings as for WLAN/NAV**



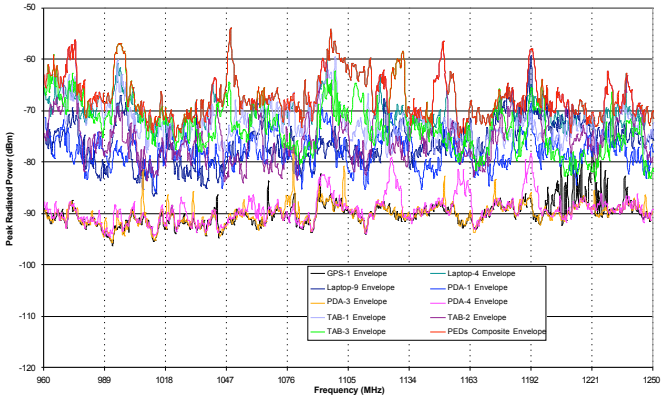
FRS Radios

GMRS Radios

Aviation Safety EME

Portable Electronic Devices (Integrated WLAN)

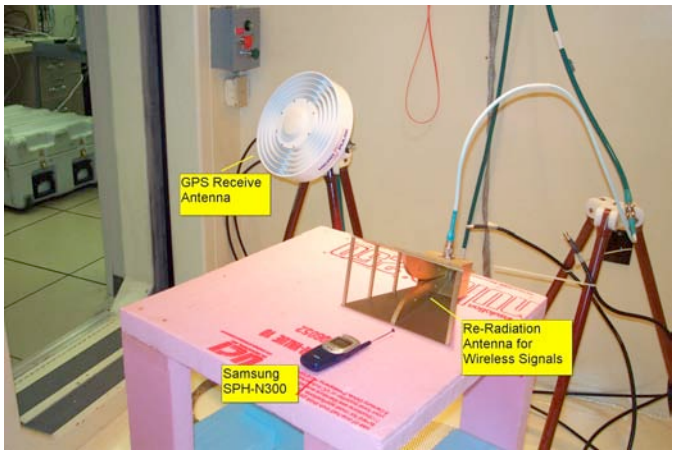
- **Reimbursable FAA Interagency Agreement DFTA03-96-X-90001 & SAAP project**
- **Extend prior WLAN device measurement & risk analysis process to portable devices with *integrated* WLAN devices**
- **Measurements included IEEE 802.11a/b and Bluetooth wireless technologies**
- **Consumer grade wireless laptops, tablet PCs and PDA's were tested**
- **Similar findings as prior WLAN studies**



Aviation Safety EME

Portable Electronic Devices (GPS Phone EMI)

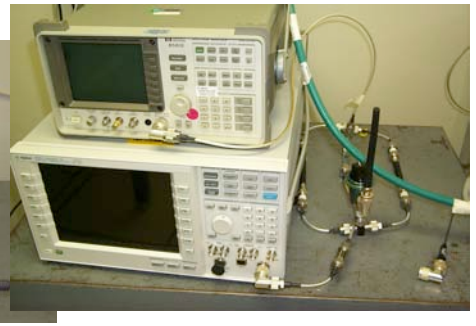
- **Reimbursable FAA Interagency Agreement DFTA03-96-X-90001 & SAAP**
- **Extend prior measurement & risk analysis process for cell phones to a specific phone model in GPS band**
- **Testing based on actual GPS phone interference incident in small aircraft with 3 different GPS radios using 3 different GPS antennas**
- **Samsung E-911 enabled cell phone, purchased via Internet auction**
- **Findings indicated spurious emissions from this phone were within FCC limits**
- **Considering interference path loss, can result in negative safety margins, thus high probability of interference**



Aviation Safety EME

Portable Electronic Devices (3G Cell Phones)

- **Reimbursable FAA Interagency Agreement DFTA03-96-X-90001 & SAAP project**
- **Extend prior measurement & risk analysis process for cell phones to 3G cell phone technology**
- **Measurements will include CDMA2000, and GSM/GPRS/PCS cellular technologies**
- **Consumer grade cellular phones are currently being tested**
- **Acquired Agilent 8960 Base Station Simulator to control the cell phones for testing**



Aviation Safety EME

Ultrawideband (UWB) EMI Assessment

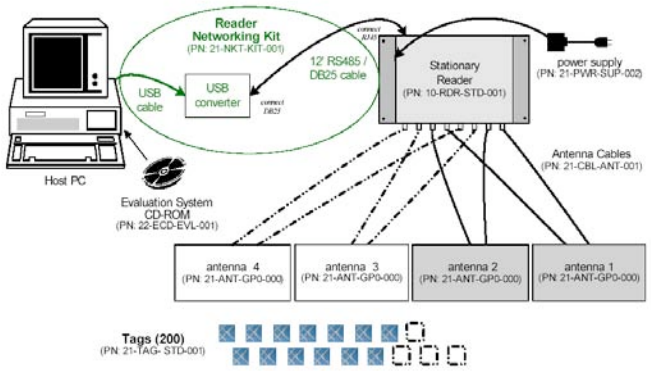
- Objective was to assess the effect of UWB signals on aircraft radio systems
- Funding provided through Aviation Safety and HQ Code M Office of Spectrum Management
- Partnership with United Airlines, Eagles Wings, Inc., Skywest Airlines, FAA
- Recently completed interference path loss measurements (IPL) on United Airlines B747-400 at San Francisco Airport (May 2004)
- IPL measurements were in-flight measurements at 3 different altitudes to determine if passenger cabin pressurization significantly affects IPL
- Study conclusions:
  - For aircraft radios operating < 960 MHz, demonstrated aircraft radio interference at and below UWB levels allowed by the FCC
  - For aircraft radios operating > 960 MHz, demonstrated aircraft radio interference above UWB levels allowed by the FCC

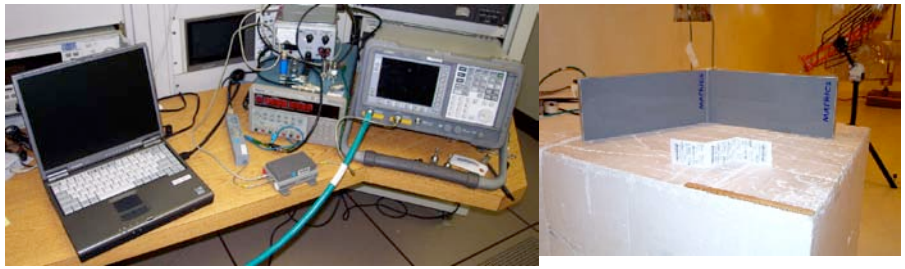
Aviation Safety EME

Delta Cooperative Agreement NCC-1-381

- **Collaboration with University of Mississippi to develop computational electromagnetic model of interference path loss prediction**
- **Interference path loss measurements on Delta Airlines revenue service aircraft at Hartsfield Atlanta airport**
- **Transmitter signal measurements**
- **RFID Testing**
  - **NASA performed spurious radiated emission measurements on a Matrics 10-RDR-STD-001 RFID reader system and three compatible RFID tags.**
  - **The RFID equipment was part of a Delta Bag-Tag evaluation project**
  - **Testing performed during June 2004**

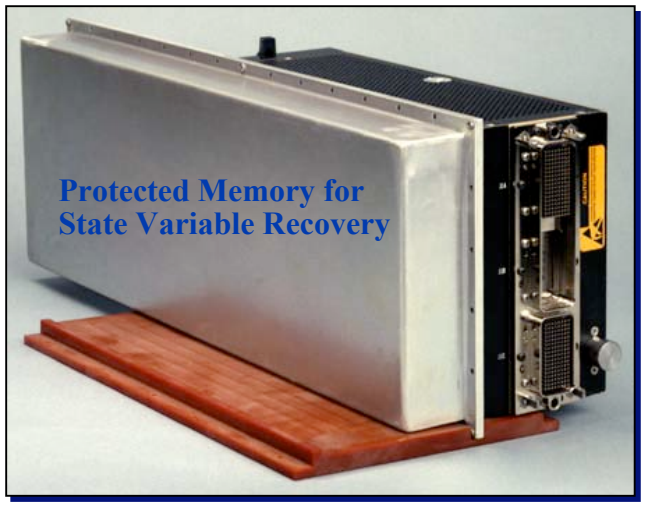
Evaluation System Setup Diagram





Aviation Safety EME

NASA/Honeywell Recoverable Computer

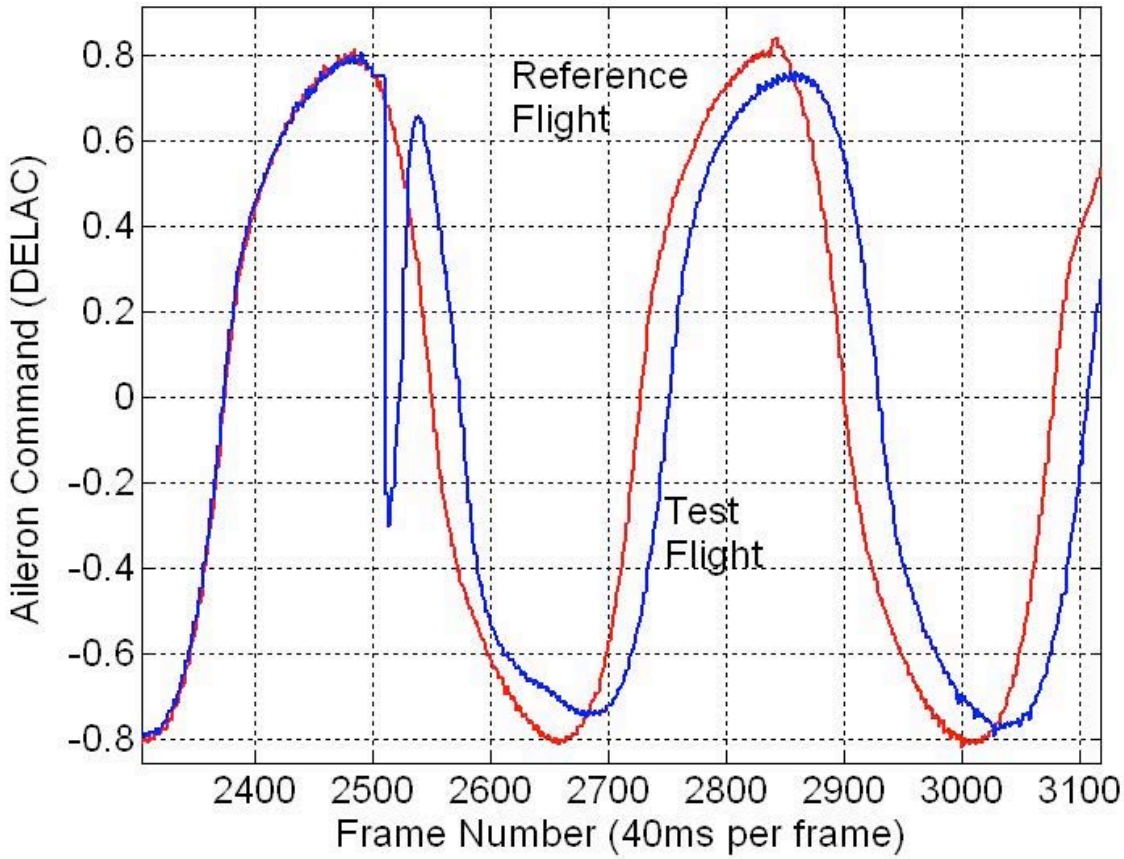


- **Develop and Demonstrate Controller that can Recover from Transient Disturbances**
  - **Based on B777 AIMS CPM Architecture**
  - **Includes Implementation of Honeywell Patents for Rapid Recovery**
- **Rapid Recovery**
  - **Refers to computer recovery such that functions appear to be performed uninterrupted even though a soft fault occurred**
- **State variable storage to protected area (highly isolated from EME effects)**
- **Comprehensive monitoring (all faults detected within the computation frame they occur)**
- **Rapid recovery of state variable data and rapid restart of computation**
- **Recoverable computer hosts a B737 Autoland application**

Aviation Safety EME

Recoverable Computer Evaluation

Software Fault Injection, Single Fault



Aviation Safety EME

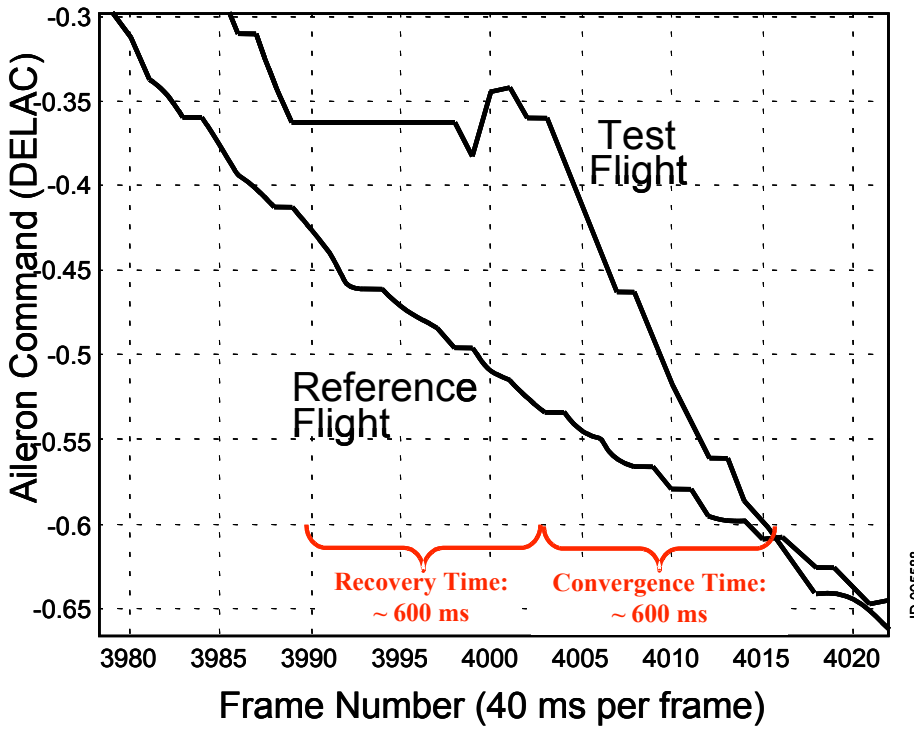
Recoverable Computer Evaluation (HIRF)

Closed-Loop HIRF Tests Performed

- **Demonstrated Effectiveness of RCS Recovery**

RCS Recovery Triggered (Detailed), Single Fault

Fault Occurred at Frame 3989 (f=640 MHz, E=850 V/m)



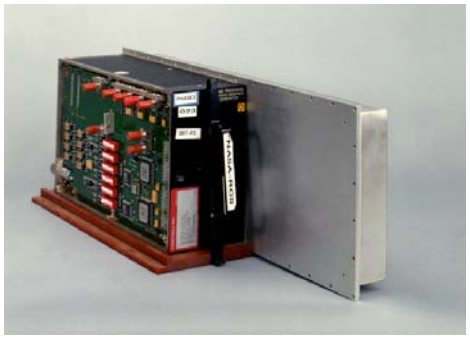
RCS in HIRF Chamber

RCS Flight Simulation For Closed-Loop Test

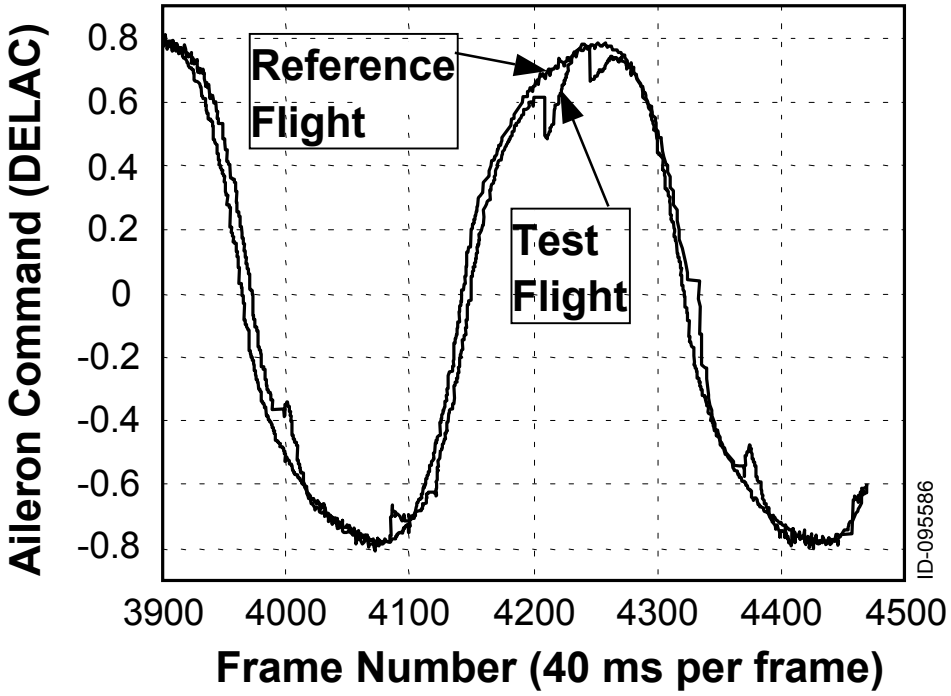
Aviation Safety EME

Recoverable Computer Evaluation (HIRF)

NASA/Honeywell Recoverable Computer System (RCS)



NASA/Honeywell RCS in HIRF Chamber



RCS Recovery Triggered, Multiple Internal Faults (f=640 MHz, E=850 V/m)

Aviation Security EME Project

Aircraft & Systems Vulnerability Mitigation — Level II

GOAL: Reduce the vulnerability of the Air Transportation System (ATS) to threats or hostile acts, and identify and inform users of potential vulnerabilities.

OBJECTIVE: Develop and advance technologies that will mitigate consequences to the aircraft from an intentional attack, and secure the flow of information to and on the aircraft

Electromagnetic Effects — Level III

GOAL: Prevent aircraft from being used as weapons; protect both air travelers and the general public from accidental or deliberate flight-path deviations caused either wholly or in part by RF attack.

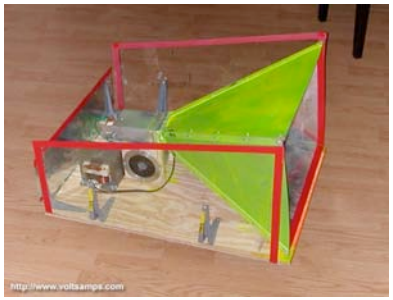
- **Benefits of Achieving EME Goal:**
  - An additional layer of aviation security
  - Improved safety and security for airline passengers
  - Potential reduction in terrorist threat
  - Reduced or eliminated effectiveness of RF attacks

OBJECTIVE: Develop technologies to further secure and harden on-board aircraft systems from intentional RF threats and enable EM surveillance of the aircraft environment.

- **Benefits of Achieving EME Objectives:**
  - Enabled Onboard RF Surveillance, Detection and Identification System
  - Improved Methods for Electromagnetic Modeling and Simulation
  - Improved RF and electronics technology threat assessments

Aviation Security EME Goal

- GOAL: Prevent aircraft from being used as weapons; protect both air travelers and the general public from accidental or deliberate flight-path deviations caused either wholly or in part by RF attack.
- OBJECTIVES: *"Develop technologies to further secure and harden on-board aircraft systems from intentional RF threats and enable EM surveillance of the aircraft environment."*



Aviation Security EME Related Programs

- NASA, Code R
  - **Aviation Safety Program: Vehicle Health Management, FAA Interagency Agreement, Aviation Safety II program**
- AFRL/DE
  - **Coral Jade program. Investigate EME for F-16 SPO, develop retrofit kits and maintenance procedures to increase RF shielding, 6 year, $7.2M**
- DOD
  - **Large Aircraft Survivability Initiative (LASI)**
    - MANPADS, infrared signature reduction, Damage Adaptive Control Systems, Large Aircraft InfraRed CounterMeasure (LAIRCM), live fire test and evaluation, full-scale 747 EM testing and characterization
- Department of Homeland Security
  - **Possible RF weapons on US infrastructure program**
- Intelligence community SIGINT research & development
- RTCA/SC-202 Portable Electronic Devices Committee
  - **Near and far term PED Technology Assessment.**
- TSA
  - **Overall transportation security concept**

Aviation Security EME Justification

EME technologies will address the following security issues:

- Spoofing/jamming/overloading of aircraft comm/nav radios
- Commercial-off-the-shelf or covert/homemade RF transmitters onboard aircraft (build & test)
- Front-door/back-door RF coupling concerns (full aircraft 747 & 757 EM testing)
- RF attack on aircraft electronic security measures
- Accurate modeling and simulation of EM field levels for aircraft and airports under simulated RF attack
- RF path loss, coupling mechanisms and general RF shielding (interference path loss measurements)
- RF surveillance, detection, identification and mitigation onboard aircraft

Aviation Security EME Approach

1. Use EME WG to help define long-term EME requirements and concepts, and identify short-term retrofit technologies
2. Work with OGAs and industry to identify RF vulnerabilities, avoid duplication, and identify synergies and collaborative opportunities
3. Leverage external capabilities in OGAs, industry and academia to enhance concept development and implementation
4. Conduct research in unique areas (not being developed elsewhere or where NASA can offer improved solutions)
5. Leverage extensive prior work in the NASA Aviation Safety program and NASA HIRF Lab to enhance research and development efforts

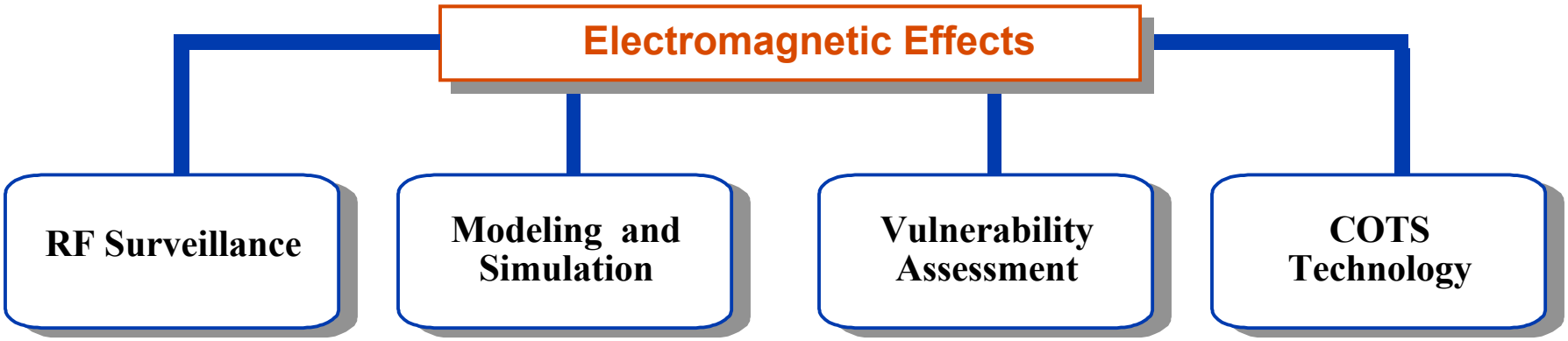
Aviation Security EME Approach (cont.)

6. Develop or enhance necessary facilities to enable end users and developers to evaluate technologies and identify improvements (e.g. NASA SAFETI Lab)
7. Integrate operational and certification issues early into concept development process to minimize risk
8. Classify RF vulnerabilities:
   - Front door coupling (overloading aircraft receivers, spoofing, onboard hostile transmitters, narrowband threats)
   - Back door coupling (general HPM threats, wideband RF sources)

Technical Challenges

1. Developing a low-cost, maintainable, certifiable RF surveillance system that can detect, locate and identify unauthorized transmitters
2. Quantifying intentional emissions from an assortment covert hostile transmitters
3. Complete EM characterization of representative commercial aircraft
4. Pushing the envelope and validation of new computational electromagnetic modeling techniques
5. Prioritize vast amounts of intelligence and technical data related to HPM weapon technology, commercial high-power RF components and systems
6. Analyzing a large amount of measured data of EM shielding, coupling and propagation for aircraft
7. Develop low-cost retrofit kits or upgrade procedures to improve general RF shielding
8. Developing a closed-loop HIRF testing capability for 747 avionics

EME Focus Areas (WBS)



- Integrate with a vehicle health management system.
- Provide detection and identification capabilities to flight crew.
- Provide a trigger for possible EMI events.
- Supplemental handheld detectors for flight attendants/flight crew

- Airport/aircraft RF propagation analysis, attack scenarios
- Provide EM certification software tools and procedures.
- Design smarter and more efficient certification plans and coupling experiments
- Develop new statistical, probabilistic, Monte Carlo or topological numerical techniques.

- Gather & analyze intelligence data on HPM & RF weapons, devices, technology and illicit usage
- Closed loop HIRF tests
- Low power full aircraft EM testing
- Develop and test retrofit kits
- Update DO-160D HIRF standards

- Identify specific vulnerabilities of aircraft avionics
- Demonstrate spoofing or jamming aircraft radios
- Construct and test covert and homemade RF devices
- GPS jamming countermeasures
- RF devices defeating electronic security measures

RF Surveillance

- Design a prototype SIGINT RF surveillance system for onboard aircraft
- Leverage prior work in signal collection, identification, direction finding and signal intelligence from intelligence community
- Scans frequency spectrum from about 100 MHz – 7 GHz
- Capable of direction finding (DF) to locate regions inside passernger cabin containing unauthorized transmitters
- Could be supplemented with flight attendant handheld detector
- Notifies pilot and/or flight crew regarding unidentified or unknown signals for possible EMI event or threat
- Interfaces with vehicle health management system
- Low cost, easily installed, little to no maintenance, fully automated
- Software upgradable
- Multipath interference in aircraft cabin can present DF difficulties
- Consider absorptively loading passenger cabin through carbon loaded seat cushions, panels, bulkheads, insulation, etc. to reduce multipath interference

Modeling and Simulation

- Update Joint Spectrum Center Graphical Analysis Tool for EME's (GATE) model and Joint E3 Evaluation Tool (JEET) emitter CONUS databases to specifically include all commercial RF emitters especially near airports and airfields
- Develop GATE and JEET model replacement called Integrated Intersite Model (IIM) for E3 analysis
- Validate JSC ARAAP modeling tool with interference path loss measurements (IPL)
- Develop expert system computational electromagnetic modeling tool for commercial aircraft E3 analysis
- Airport/aircraft RF propagation analysis, attack scenarios using COTS software
- Develop new statistical, probabilistic, Monte Carlo or topological numerical techniques.

Vulnerability Assessment

- Continuous intelligence analysis using JWICS and classified reports
- LASI program full-up aircraft EM tests and RF attack scenarios
- Closed pilot-in-the-loop HIRF/EMI tests (at conclusion of LASI program)
- Materials research and development work (Ken Dudley, ERB)
  - Investigate RF shielding/transmission of conductive paints, transparent conductive window films, etc., as applied to current and future aircraft bulkheads, windows, floor panels, etc.
  - Investigate RF shielding/transmission of common building materials such as drywall, concrete, brick, wood, asphalt shingles, glass, insulation, etc. for airports (and doubling for Homeland Security applications of EME)
  - Develop a comprehensive database of RF transmission for all of these materials that can be used by computational EM modeling tools
- Additional IPL measurements (through LASI program or otherwise)
- Receiver susceptibility measurements
- Develop a hardened (jam resistant) aircraft radio receiver
- Determine J/S signal ratios required for interference

Commercial Off-the-Shelf Technology

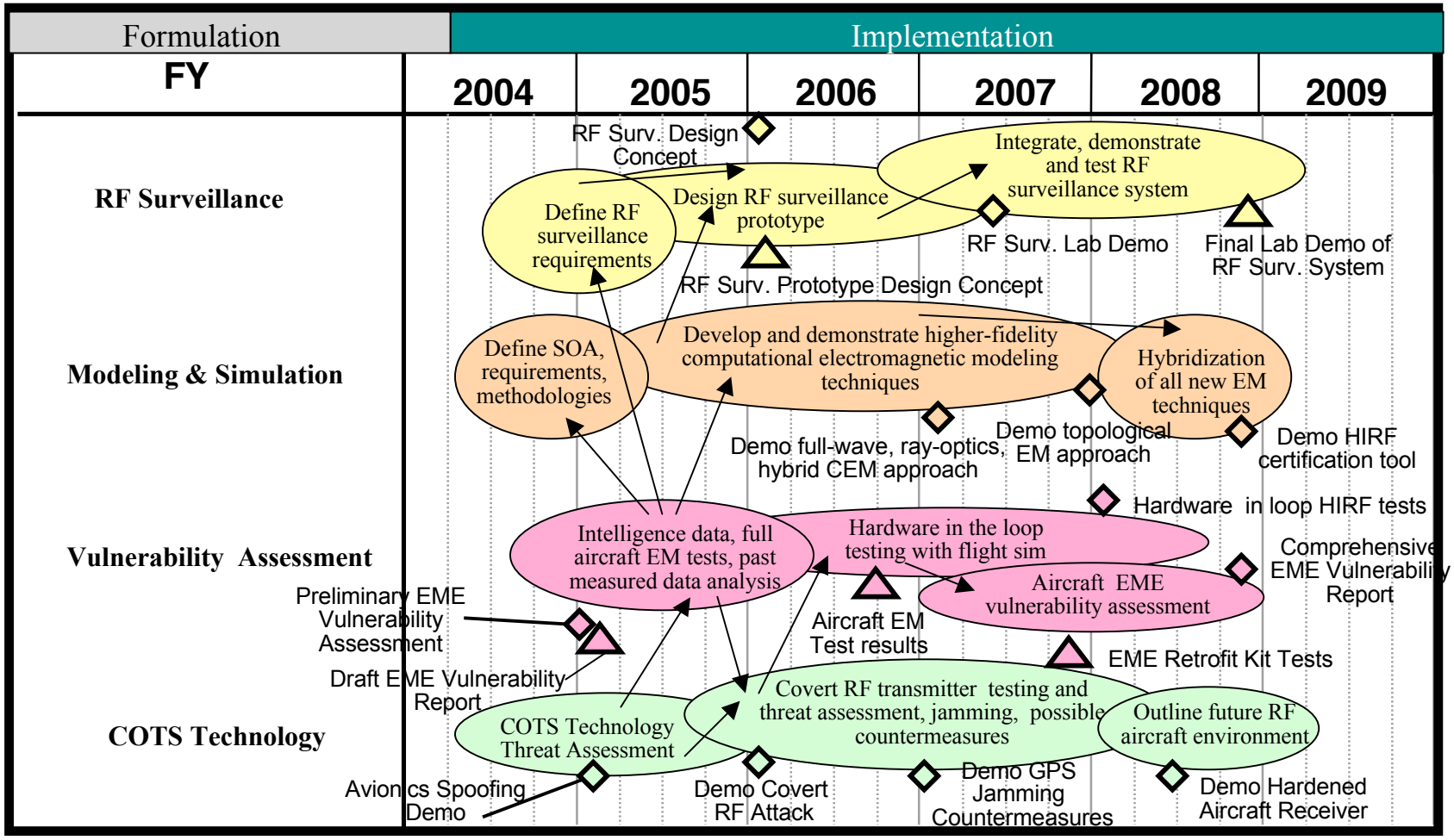
- Identify specific aircraft vulnerabilities
- Build and demonstrate various covert transmitters using publicly available plans
- Electronic circuit plans already downloaded from well-known hacker web-site
- Purchased a package of additional circuit plans off Internet for $100
- Currently building two different GPS jammer designs
- Considering other unauthorized transmitters:
  - 802.11 jammers
  - AM/FM radio jammers
  - MIRT traffic light changers
  - Cell phone jammers
  - Radar jammers
- Demonstrate COTS aircraft ramp test set spoofing capabilities
- Working with local charter aircraft companies and employing local pilot services to design and execute experiments
- Continue work evaluating identifying interference risks of Portable Electronic Devices, UWB technology and emerging wireless technologies (RFID, software defined radios, etc.)

Aviation Security EME

FY04 Accomplishments

- **Interagency Agreement and procurement with AFRL/DE for RF Threat Assessment and program planning assistance**
- **Interagency Agreement with Joint Spectrum Center for modeling & simulation efforts**
- **Procurement of Garmin GNS530 GPS avionics unit**
- **Developed a security classification guide for EME project**
- **Obtained security clearances for HIRF Lab staff**
- **Developed secure facility for part-time classified information processing and classified document storage**
- **Secure telephone equipment**
- **Co-sponsored interference path loss measurements (5/2004) for B747-400 in flight at San Francisco airport**
- **Brought on two ODU graduate students through GSRP**
- **Several computer and lab equipment procurements for electronic/RF test equipment, lab supplies, etc.**
- **Numerous meetings with OGAs, conferences, and workshops**

Roadmap


Formulation
Implementation
FY
2004
2005
2006
2007
2008
2009
RF Surveillance
Modeling & Simulation
Vulnerability Assessment
COTS Technology
RF Surv. Design Concept
Define RF surveillance requirements
Design RF surveillance prototype
Integrate, demonstrate and test RF surveillance system
RF Surv. Lab Demo
Final Lab Demo of RF Surv. System
RF Surv. Prototype Design Concept
Define SOA, requirements, methodologies
Develop and demonstrate higher-fidelity computational electromagnetic modeling techniques
Hybridization of all new EM techniques
Demo full-wave, ray-optics, hybrid CEM approach
Demo topological EM approach
Demo HIRF certification tool
Hardware in loop HIRF tests
Intelligence data, full aircraft EM tests, past measured data analysis
Hardware in the loop testing with flight sim
Aircraft EME vulnerability assessment
Comprehensive EME Vulnerability Report
Preliminary EME Vulnerability Assessment
Aircraft EM Test results
EME Retrofit Kit Tests
Draft EME Vulnerability Report
COTS Technology Threat Assessment
Covert RF transmitter testing and threat assessment, jamming, possible countermeasures
Outline future RF aircraft environment
Avionics Spoofing Demo
Demo Covert RF Attack
Demo GPS Jamming Countermeasures
Demo Hardened Aircraft Receiver
Level 2 Milestone
Level 3 Milestone

Future Plans

- Be aware of HIRF Lab capabilities
- Keep HIRF Lab in mind for future mission proposal opportunities
- Would like to expand our work into spacecraft EMI, automotive industry EMI and perhaps even commercial product EMI
- EME for other US infrastructure targets (i.e. Homeland Security)
- Continue work in Aviation Safety & Security program
- Become more closely involved in intelligence community related to RF weapons and E3
- E3 work in collaboration with DoD and other Federal agencies
- Market HIRF Lab externally from NASA at conferences, workshops, etc.
- Develop NASA Agency-wide RF/Microwave Technology Center (primarily a virtual center) to co-locate information about RF and microwave capabilities at the various NASA centers

Summary

Consider working in the HIRF Lab?

Questions?