Reliability Information Analysis Center
Corrosion Capabilities Briefing

25 March 2009

Joseph Hazeltine, PE- Director RIAC

Tim Bair- Director iMAST

Agenda

- **Overview of RIAC**
- **RIAC Corrosion Test Capabilities**
- **Overview of ARL**
  - History and Mission of ARL
  - Core Research Areas
- **ARL Corrosion Capabilities**
- **The Pennsylvania State University Corrosion Related Resources**
  - University Facilities and Research Groups
  - University Programs
- **Additional Related Topics of Interest**
  - Repair Technology Examples
- **Summary**
- **Questions**

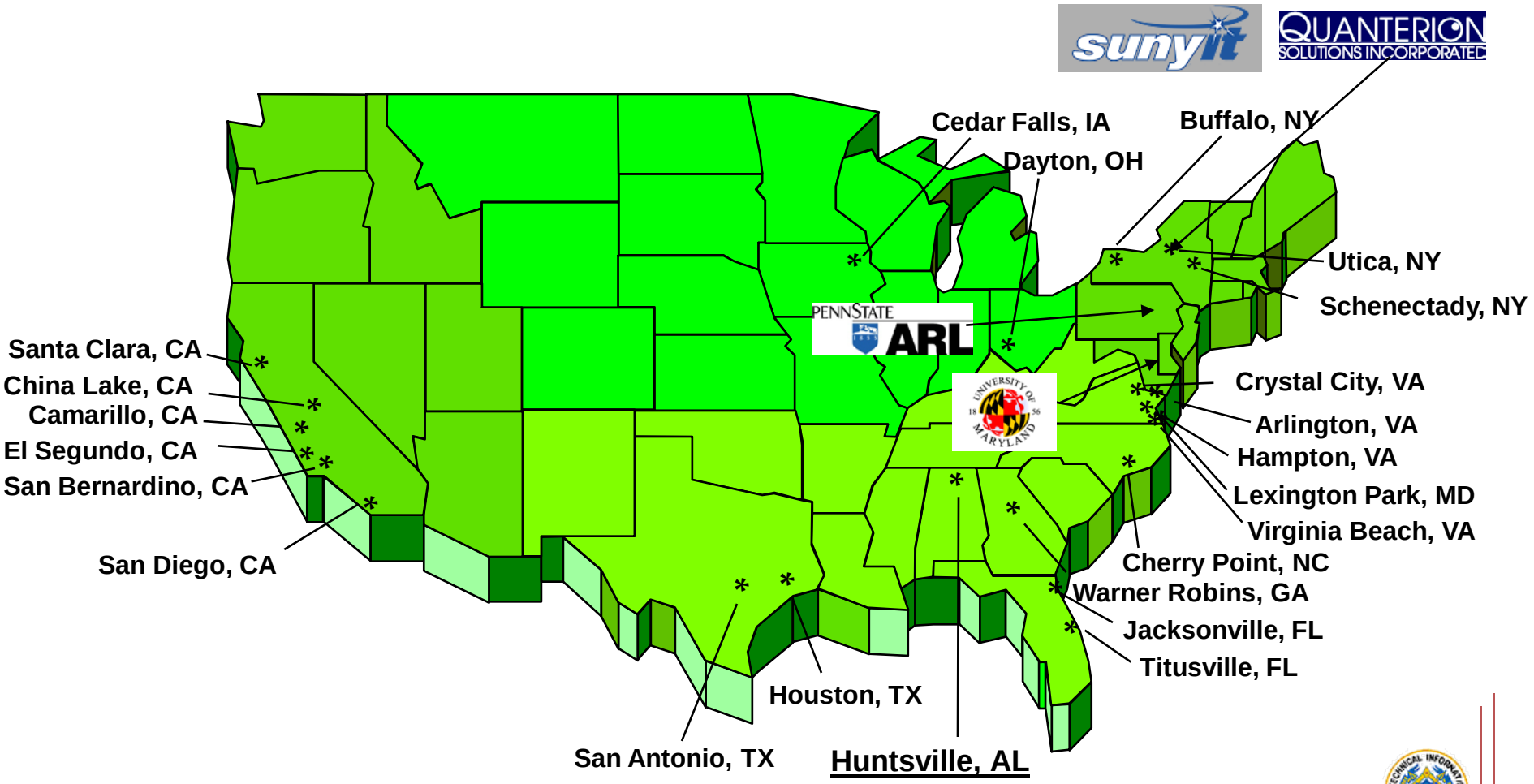
What is the **R**eliability **I**nformation **A**nalysis **C**enter (RIAC)?

RIAC is one of 10 DoD **Information Analysis Centers** (**IACs**) managed by the Defense Technical Information Center (DTIC). RIAC' s charter includes **Reliability**, **Maintainability**, **Quality**, **Supportability**, and **Interoperability (RMQSI)**.

RIAC Quick Facts

Attribute	Metric
Technologies	Reliability, Maintainability, Quality, Supportability, and Interoperability (RMQSI)
Library	150,000 Documents
User Base	>20,000
Products	85 (15 new ones since 2006, 10 under development)
Training	25 Off-the-Shelf Courses Regular Quarterly Open-Presentation Courses
Research Projects Underway	10 new reliability engineering tools under development
	~60 Subscription Accounts in process
	~140 Technical Area Tasks in process
Staff	~2000 Staff Members (SMEs) Available
Impact	Data, Tools, and Guidelines Used on International Level

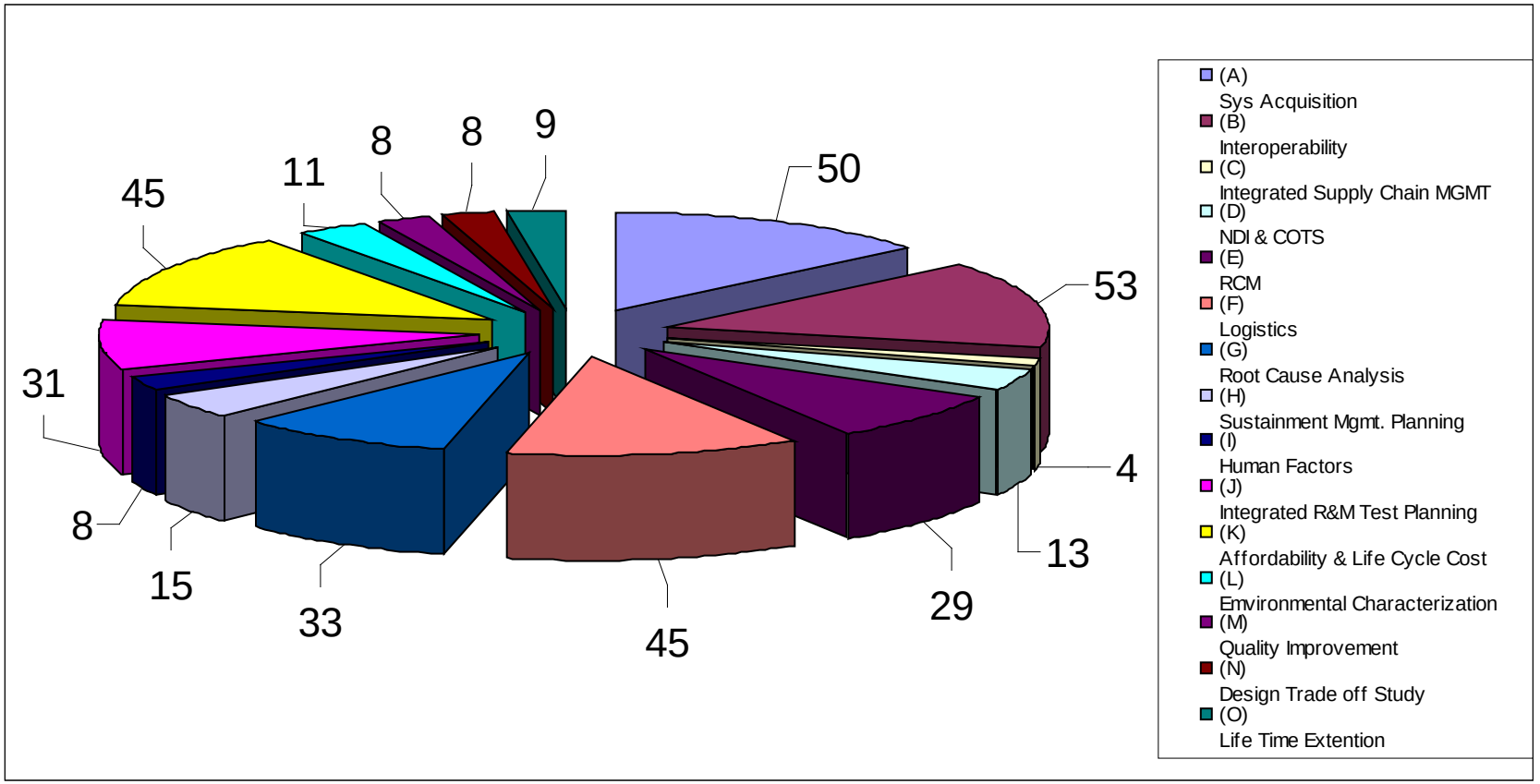
RIAC Locations



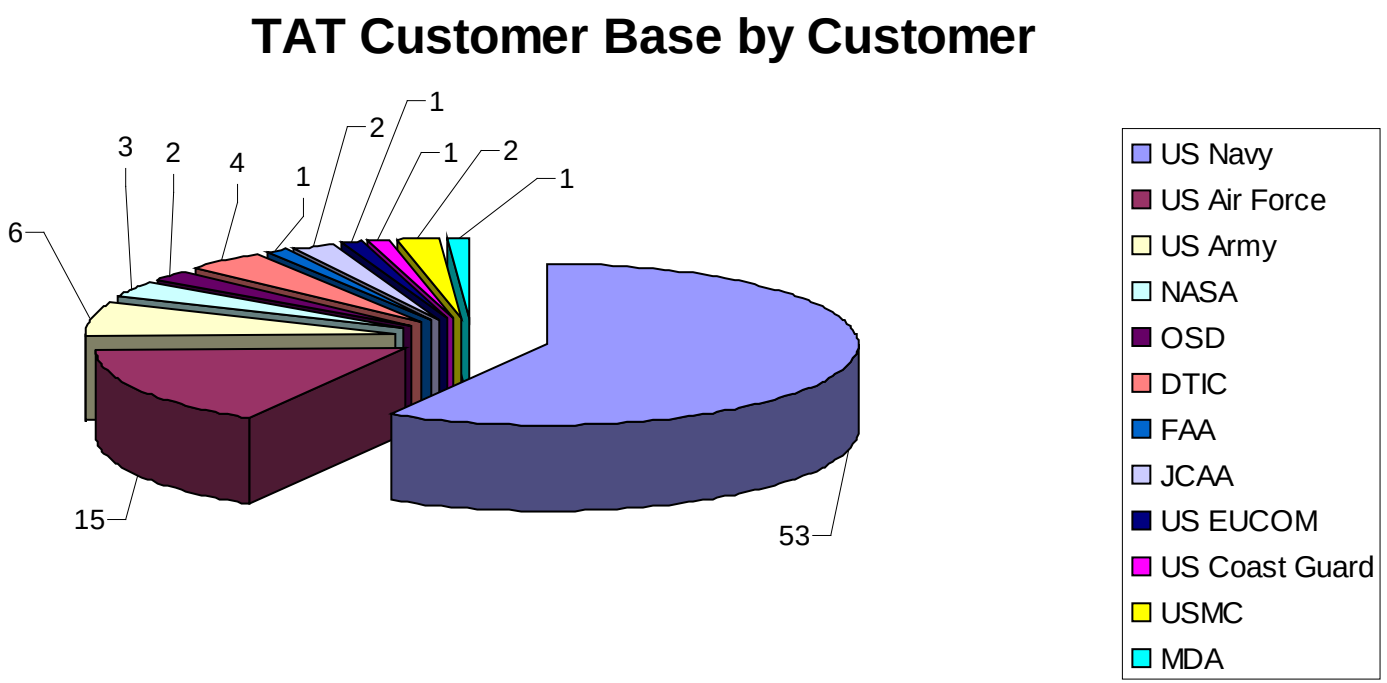
RIAC Resources

Team Member	Testing	Library	Laboratories	Supporting Centers
Wyle Laboratories	Many Locations in CONUS	Company	Failure Analysis, Environmental, EMI and others	Total Ownership Cost, RCM/Aging Systems, Life Sciences
UMD Center of Risk and Reliability	Many at UMD Including CALCE	Major University	Failure Analysis	CALCE, Risk, SW Rel, Structures
PSU Applied Research Lab	Prognostics and Mechanical	Major University	Failure Analysis	iMAST, Reptech, Supply Chain, Mgmt
SUNY Institute of Technology	SUNY 64 Campus Network	SUNY 64 Campus Network	Computer Related	Nanotechnology, Electronics Packaging, Sensors

How is **RIAC** being Used?



Who is Using **RIAC**?



Total Number of TATs Assigned- 91
(working 10 new TATs including one on Corrosion)

Electrolytic Corrosion

- Also called General Corrosion
- Most common form with uniform loss of metal
- Long term test programs
- Can be accelerated with increased temperature or relative humidity
- Simulate in Temperature/Humidity test systems ranging from 4 ft^3 to 8500 ft^3

Wyle's 4,500 ft^3 thermal chamber

Salt Water Corrosion

- Mil-Std 810F- 48 hour test
- ASTM B117- 28 day test
- High humidity and 5% salt solution
- Chamber sizes from to
- Generally run multiple coupons with different coatings
- Electrolytic chemical reaction

Salt Fog testing on a missile launcher

Other Corrosive Environments

- Acetic Acid
- Hydrochloric acid (HCl)
- Sulfuric Acid (H^2SO_4)
- Sulfur Dioxide Gas (So_2)
- Called out as fluid compatibility tests both in Aero/DoD and automotive testing
- Usually a short term exposure
- Use special chamber that we sacrifice

Galvanic Corrosion

- Dissimilar metals in an electrolytic solution
- Following Galvanic Table (See Mil-Std-889)
    - From Magnesium to graphite
- In some environments use sacrificial anode like zinc
- Perform in temp/humidity chambers
- Can accelerate with an electric circuit

Wyle's blowing rain test site

Intergranular Corrosion

- Can be caused by poor processing during manufacture
- Can be caused by wrong coatings
- Also caused by poor heat treatment
- Also an issue with over-etching
- Evaluate in temp/humidity chamber or salt fog chamber

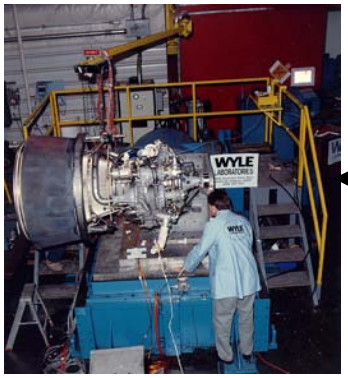
Localized Corrosion

- Pitting- small areas with high corrosion rates
- Crevice corrosion- again highly localized and concentrated
- Undercoating corrosion- accelerated again due to high concentration
- Galling and Impingement- due to mechanical wear or damage
- Can use our large hot/cold water flow loops

Post Salt Fog Test results on fittings

Stress Corrosion

- One common type is chloride stress corrosion cracking
  - Requires chlorine, oxygen, austenitic stainless steel, higher temperature and tensile stress
- UMd studying effects of high and low cycle fatigue as an corrosion accelerant
- Also present in Copper alloys with ammonia, higher humidity and So_2
- Also simulated in specialty chambers



RL 10 Engine setup for Vibration test

Corrosion Mitigation

- Limit accelerating factors
  - Temp, pH, Oxygen, fluid velocity and suspended solids
- Chose materials with corrosion in mind
- Use inhibitors
  - Phosphates, zinc, nitrates, and silica
- Use coatings
- Control of water chemistry
- All have been tested in projects at Wyle

Impact

- Corrosion is a big problem
- US DOT estimated costs at @$276B/year in 2001
- DoD estimate is $20B/yr
- Does not include the environmental impact
- Is corrosion a material problem or a reliability problem?
    - We believe it is both
- RIAC has TAT to study corrosion as a reliability engineering issue focusing on education system
- RIAC is working a new USAF wide TAT on Corrosion Engineering

PENNSTATE ARL

Applied Research Laboratory
The Pennsylvania State University

Corrosion Prevention and Control Related Activities of RIAC and ARL - Penn State University

PRESENTED BY:

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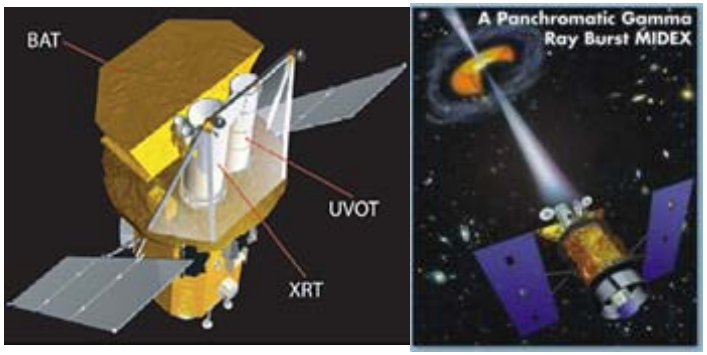
RIAC

ARL Background and Scope



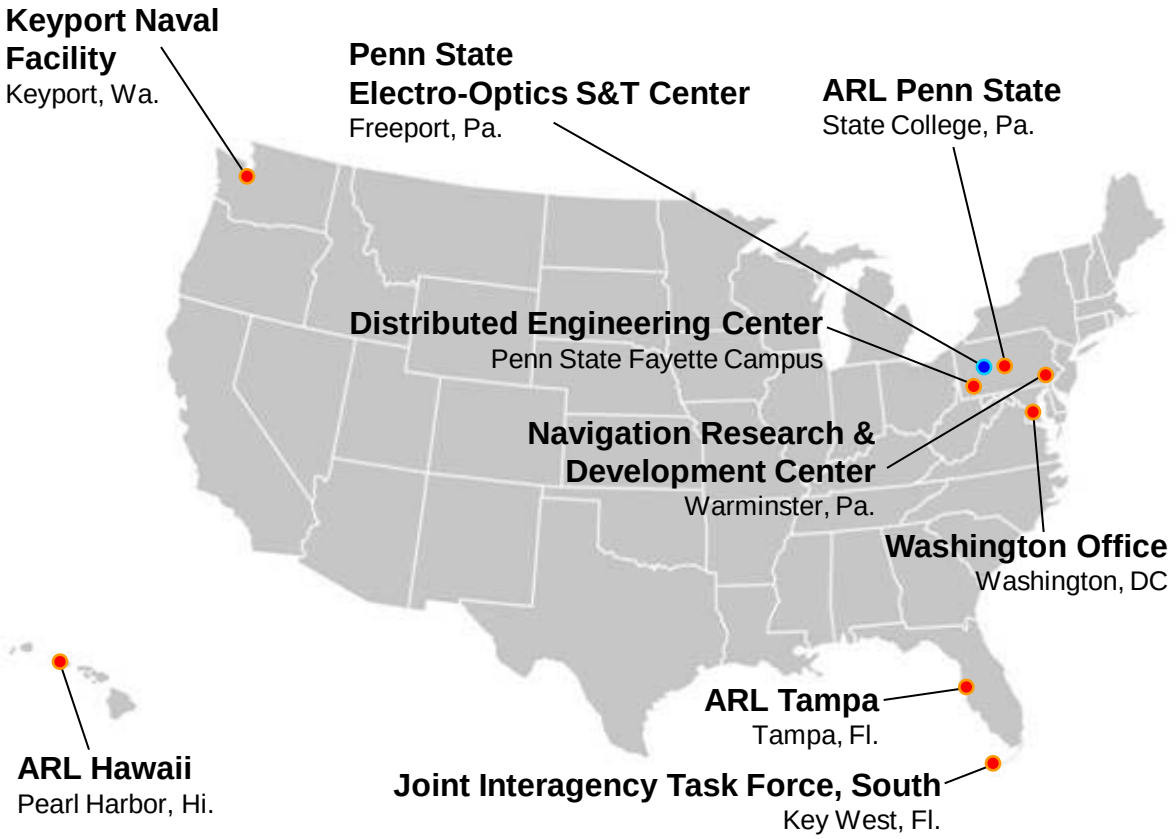
- **Background**
  - Established in 1945 by the Navy; designated an University Affiliated Research Center in 1996
  - 1124 faculty/engineers, staff, and students
  - Research expenditures FY2008: $145M
  - Classified facilities and programs
- **Technologies and Core Competencies**
  - Communications and information systems
  - Navigation, inertial measurement, GPS
  - Intelligent autonomous systems—UUV's
  - Materials, structures, manufacturing S&T
  - Power and energy systems
  - Undersea weapons and counter-weapons
  - Fluid dynamics and computational mechanics
  - Acoustics
    - – Intercollege Graduate Program Collaboration

Locations


APPLIED RESEARCH LABORATORY BUILDING


APPLIED SCIENCE BUILDING


GARFIELD THOMAS WATER TUNNEL




NAVIGATION RESEARCH & DEVELOPMENT CENTER


ARL WEST III


ARL WEST I

Mission and Organization

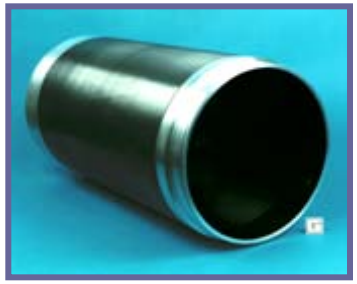
ARL's Materials & Manufacturing Office

MISSION

To be the preeminent source of innovative materials, processes, and design technologies for affordable, high performance DoD systems.

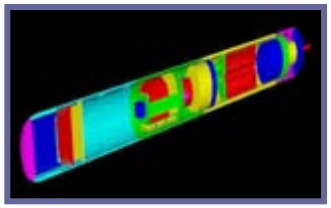
Materials Processing

- Material Design and Characterization
- Process Development
- Advanced Coatings



Advanced Composites

- Marine, Land, and Aerospace Systems
  - Design and Analysis
  - Materials Characterization and Quality Control
  - Process Optimization
  - NDE, Repair



Manufacturing Systems

- Automated Conceptual Design/Trade Space Exploration
- Simulation and Modeling for Manufacturing
- Shearography, Spectrometry, Inspection, NDT
- Environmental Technology

Laser Processing

- Laser Physics
- Process Technology
- System Integration

Systems & Operations Automation

- Condition Based Maintenance
- Sense and Respond Logistics
- Integrated Health Management

MAJOR PROGRAMS

iMAST, Drivetrain Technology Center,
DTRA University Partnership, Laser Processing Consortium

ARL's Corrosion Capabilities

- Cyclic Corrosion Chambers
  - Salt Fog: Singleton CCT-10 and Q-Labs CCT 300
    - ASTM B117, GM 9540P, SAE J2334, and additional variants
- Alternate Immersion Chamber
  - Customized automated immersion tank for stress corrosion cracking (ASTM G44)
- Electrochemical (DC & AC)
  - Gamry PC4 Potentiostat, EG&G 273A Potentiostat (for high current applications)
    - Electrochemical polarization, corrosion rate, galvanic corrosion, pitting resistance, Electrochemical Impedance Spectroscopy (EIS)
- High Temperature Corrosion
  - Equipment: Dean's Rig (Type I and II hot corrosion)
  - Controlled humidity thermal cycling
  - Thermal cycling quench furnace
- Related Equipment
  - High impedance voltmeter ($Z=10^{13}\ \Omega$)
  - Conductivity/pH meters
  - Crevice corrosion test cells
  - Micro probe reference electrodes (50 micron)
- Digital Image Analysis
  - Clemex Professional (Quantitative data on corrosion and statistical analysis)
- Varity of Coating Design & Development, Application & Removal Development
  - Polymer,Ceramic, Metallic
  - Hybrid and Composite Systems

The Pennsylvania State University Resources

- Extensive Materials Characterization and Evaluation Through MCL Network

Microscopy
- •Atomic Force Microscopy
- •Energy Dispersive X-Ray Spectroscopy
- •Focused Ion Beam
- •Near-Field Scanning Optical Microscopy
- •Optical Profilometry
- •Orientation Imaging Microscopy
- •Scanning Electron Microscopy
- •Transmission Electron Microscopy

Surface and Thin Film
- •Auger Electron Spectroscopy
- •Confocal Raman Spectroscopy
- •Electron Probe MicroAnalysis
- •Energy Dispersive X-Ray Spectroscopy
- •X-ray Photoelectron Spectroscopy

Structural Analysis
- •Small Angle X-Ray Scattering
- •X-Ray Diffraction

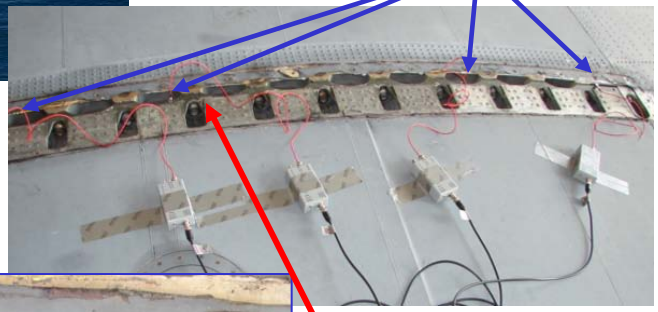
Optical Spectroscopy
- •Fourier Transform Infrared Spectroscopy (FT-IR)
  - •FT-IR Macro Analysis
  - •FT-IR Microscopy
- •Ultraviolet-Visible Spectroscopy (UV-Vis)

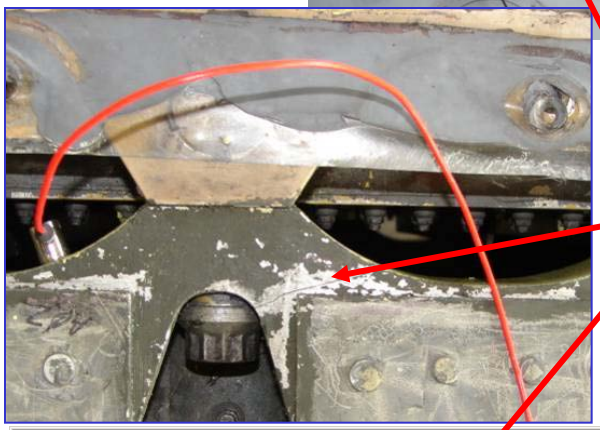
Chemical Analysis
- •Inductively Coupled Plasma-Atomic Emission Spectrometry
- •Inductively Coupled Plasma-Mass Spectrometry
- •Ion Chromatography

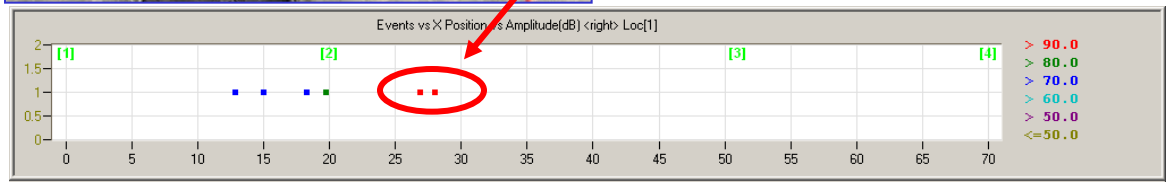
Physical Property Determination
- •Dielectric Property Measurement Lab
- •Polarization & Strain Measurement Lab
- •Particle Characterization Lab
- •Multi-Point BET Analyzer
- •Mechanical Testing Laboratory
- •Thermal Analysis Lab (DSC/DTA/TGA)

- Fundamental Corrosion Research
  - Penn State Materials Science Department: Center for Electrochemical Science and Technology (Digby McDonald)
  - Penn State Engineering Science and Mechanics Department: Corrosion Research Laboratory (Barbara Shaw)
    - Industry Outreach with Corrosion Short Courses for Engineers (offered for 13 consecutive years)

In-Situ Acoustic Emission Monitoring for Crack Detection







Objective: Reduce life cycle costs associated with the current labor-intensive, time-based maintenance of the C-130 rainbow fitting by implementing a non-destructive evaluation technique that provides a reliable crack detection capability.

Technical Goals for Phase I:

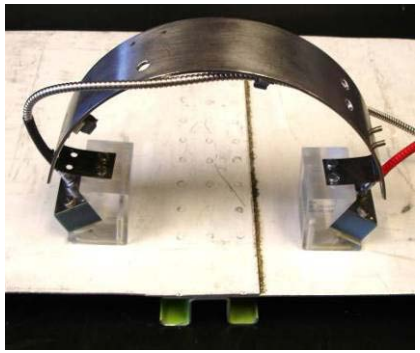
- Evaluate two NDI technologies for detection of cracks in rainbow fittings
- Demonstrate sensitivity to hidden cracks and globally locate crack position

Funding: AFRL

Accomplishments:

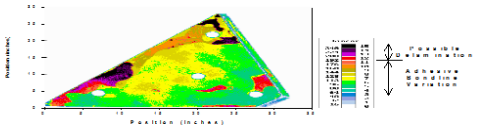
- Laboratory testing showed high sensitivity to crack detection and location
- Field testing at Little Rock AFB demonstrated in-situ detection and location of cracked rainbow fitting during fuel loading
- In-situ full-scale test monitoring at Mercer Engineering demonstrated AE noise isolation and AE source location during cyclic loading

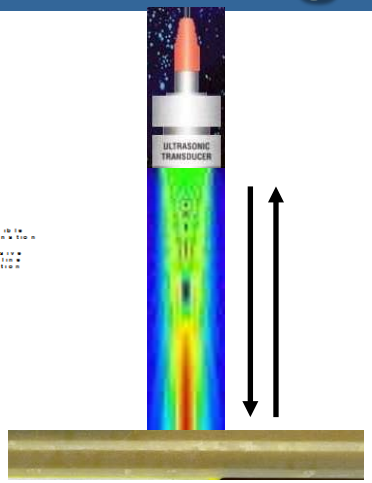
Advanced Ultrasonic NDI Technologies



Guided Wave Hopping Probe

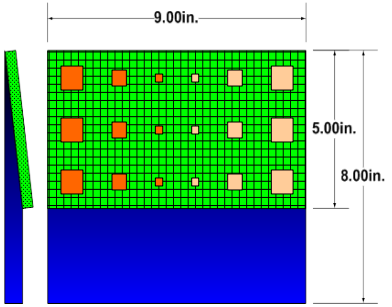
Multilayer Armor

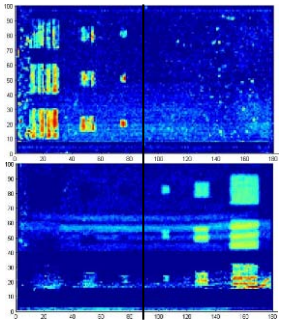




Waveform Modeling

DDG-1000 Bonded Joint





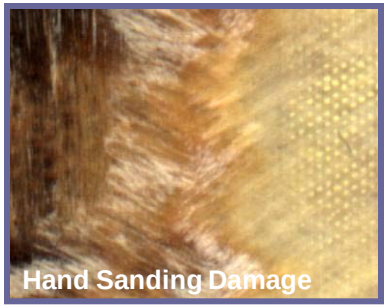
Steel-Adhesive Interface

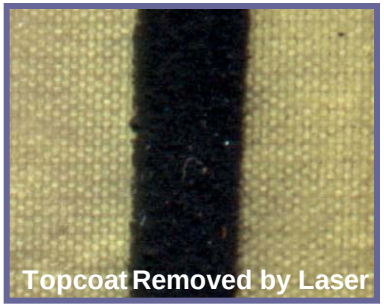
Adhesive-Composite Interface

- **Spread Spectrum Signal Processing**
  - Interface (Adhesive Bondline) Integrity Mapping
  - High Loss Materials Interrogation
  - Wide-band Transducers & Waveform Design
  - Multiple Interface Identification
- **Guided Wave Inspection**
  - Low Signal Loss, Wide-area Bondline Imaging
  - Corrosion/Crack Detection & Location
  - Hidden Structure Monitoring
- **Acoustic Emission Monitoring & Damage Location**
  - Early Crack/Damage Detection and Location
- **These NDI Technologies are Large-structure, Depot Capable with No Operational Risk**

Contact: Clark Moose, cam168@psu.edu, 814-863-5804

Laser-Based Coatings Removal for Repair


Hand Sanding Damage

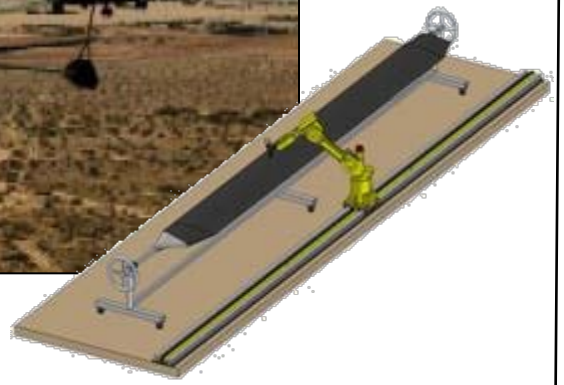

Topcoat Removed by Laser

Courtesy NUWC Keyport

Automated Rotor Blade Stripping System

- **Implementing system for laser stripping of fiberglass composite helicopter blades for repair.**
- **Large integrated program team:**
  - ARL Penn State
  - FRC East, Cherry Point
  - Sikorsky Aircraft
  - National Center for Manufacturing Sciences
  - General Lasertronics Corporation
  - NAVAIRSYSCOM 4.0, 6.0
  - NUWC Keyport
  - Koops Robotics
- **Fleet Readiness Center – East (FRC East, Cherry Point, NC) installation targeted for early 2009.**

Helicopter Blade Refurbishment



Automation of Rotorblade Paint Stripping Process

SOLUTION

- Identify an alternative depainting process for rotor blades
- Qualify the chosen process
- Design, build, and implement a commercially available automated laser-based paint stripping system with sensor feedback for substrate protection

BENEFITS

- Increase throughput *(from 22 hrs to <8 hrs per blade)*
- Reduce cost *(from $715 to <$300 per blade)*
- Eliminate substrate damage and rework
- Reduce or eliminate health and environmental concerns associated with current process
- Estimate 1.54 year payback for Depot

OBJECTIVES

- Implement an alternative depainting technology for helicopter rotor blade refurbishment.

BUSINESS STRATEGY

- Jointness: Category B -- Navy, Marines, Army
- Execution: Navy
- Performing Organization: ARL, FRC East, NCMS/CTMA, Sikorsky, NUWC Kpt, General Lasertronics, Koops Robotics
- Duration: 5 yrs
- Funding:

	FY02-FY03	FY04-FY05	FY06-FY07	TOTAL
Reptech	$226K	$250K	$240K	$814K
NCMS - ARL	--	$50K	$101K	$151K
NCMS – Total	--	$742k	$4.0M	$4.7M

NCM/CTMA received additional $$ August 2008 (unknown amount)

RELATED EFFORTS

- NCMS/CTMA Blade Stripping Project
- LanCorp SBIR: Diode Laser Removal For Interior Ship Coatings (completed 2003)

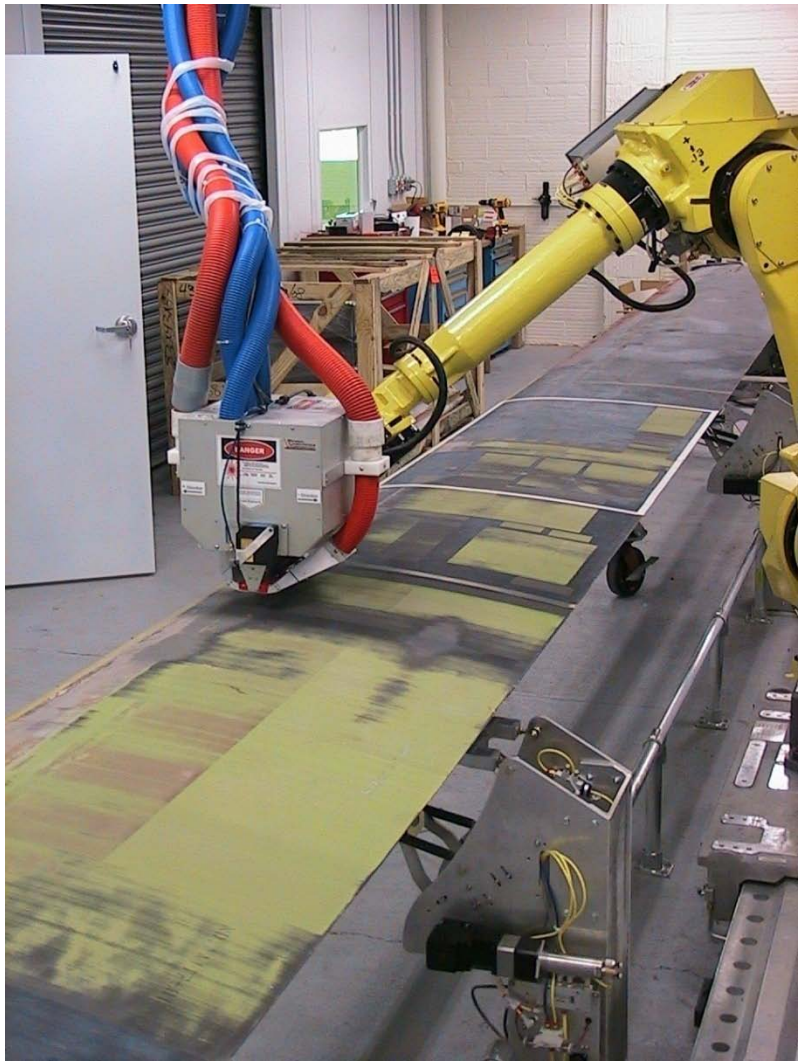
IMPLEMENTATION

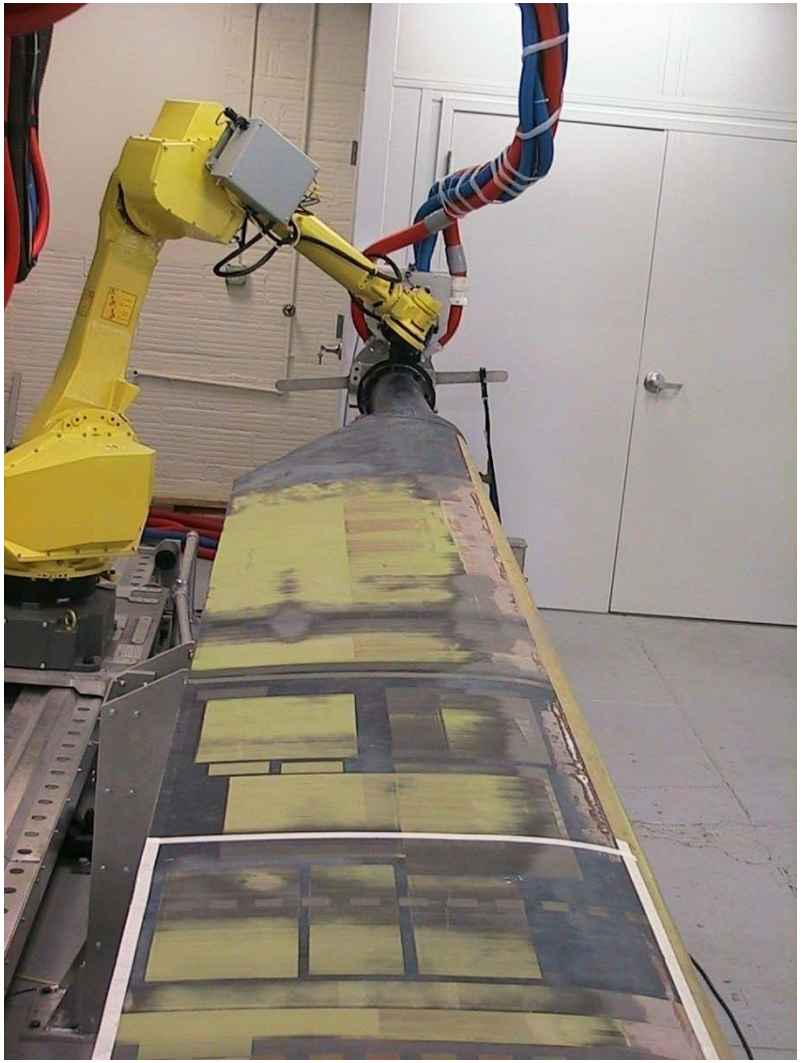
- Close cooperation with:
  - Sikorsky will ensure rapid approval through NAVAIR
  - General Lasertronics & Koops will ensure commercial outlet for technology
  - FRC East will ensure integration into production
- NCMS/CTMA brings $4.7M+ in leveraged project support
- FRC East has allocated $2.0M CPP funds for FY09 equipment purchase

PENNSTATE 1855 ARL

Progress !

Photos of ARBSS during Functional Testing - April 2008





Coating Formulation Projects

Current nonskid durability is marginal. Nonskid coatings capable of lasting 2+ deployments are needed.

Title: **Extended Durability (Type V) Nonskid Coating**

Objective: Develop a Mil-PRF-24667B, Type V nonskid coating capable of lasting through multiple deployments.

Results: Typical weight loss in cable abrasion for Type I (High Durability) nonskid coatings is 5% - 8%. Weight loss of the ARL Penn State formulation in cable abrasion is 0.5% to 0.75%.

Status: Coating is manufactured by Euclid Chemicals and will be marketed under the trade name of Flexolith 2000G. Coating is currently in qualification and is expected to be applied to a CVN flight deck (test patch) in FY09.

Payoff: $4.8 Million annual cost avoidance

High Temperature Resistant Nonskid.

Title: **High-Temp Nonskid Coatings**

Objective: Develop a Mil-PRF-24667B, Type IX (High Temp) nonskid coating for MV22 Osprey and JSF.

Results: A roller-applied nonskid coating meeting all requirements of Mil-PRF-24667B, Type IX was developed in April 2008. The coating is being evaluated by the FNC group for JSF exposure.

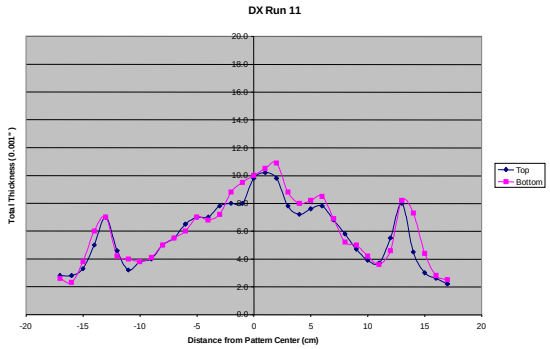
Status: Coating has been submitted to FNC program for JSF exposure. Coating will be manufactured by Euclid Chemicals, Inc.

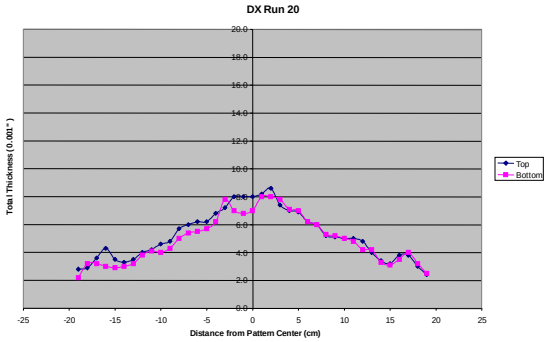
Payoff: Enable operation of MV22 and JSF aircraft on CVN and LHA/LHD platforms.

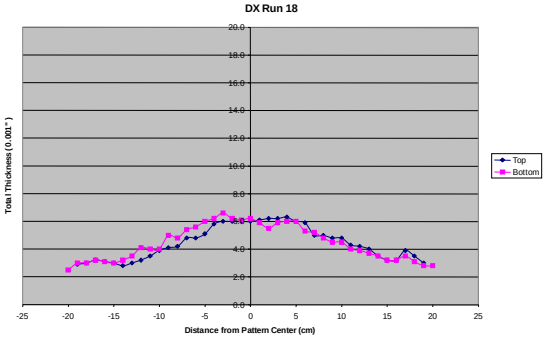
System(s): LHA/LHD, CVN

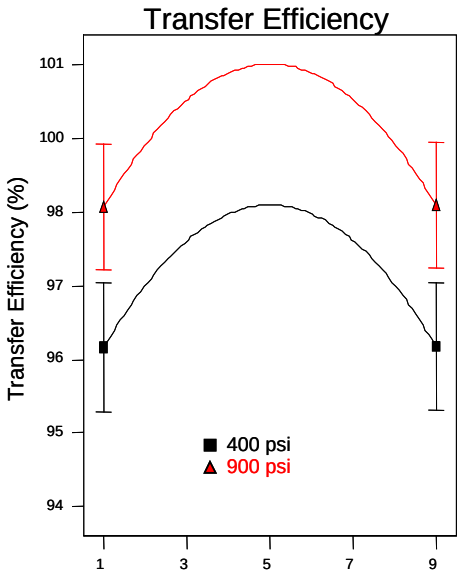
High Efficiency Paint Spray Gun Development

Optimization of pattern quality and transfer efficiency









- Solid Lines indicate mathematical prediction
- Squares and Triangles indicate actual data collected

Goal: Increase Transfer Efficiency of the airless paint spray process from 65% to 95%.

Cost Benefit: Reduce material usage by as much as 33%. This corresponds to a cost avoidance of $600K for a single medium-sized shipyard.

Environmental: Reduce VOC emissions by as much as 33%. This corresponds to a VOC reduction of 12 metric tons for a single medium-size shipyard (paint VOC content = 340 g/L).

Status: Technology is sufficiently developed to design and fabricate stationary or robot-mounted systems. Hand-held paint spray gun is still under development.

Summary

- ARL Penn State has a 64-year proud legacy of delivering advanced technology and R&D products to the DoD and NASA
- The UARC designation captures our trusted agent status and the strategic relationship that exists between Penn State and the DoD
- Our “track record” is based upon a first principles research approach and integral relationship within Penn State
- We’ve applied this for the Navy as well as DoD and other agencies in a myriad of technology areas, including Corrosion management
- Penn State fulfills a key role in developing a cadre of engineers and scientists needed for the future DoD workforce
- ARL & RIAC partnered for DoD!

Institute for Manufacturing and Sustainment Technologies

The Applied Research Laboratory
The Pennsylvania State University

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Corrosion Resistant Coatings

SH-Magnesium Transmission Gearbox Housing

Project Number:	**A2138**
Title:	**Corrosion Resistant Coatings for Magnesium Transmission Gearboxes for SH60**
Performing Activity:	iMAST / ARL Penn State
Objective:	**Develop process to apply corrosion resistant coatings that will meet refurbishment/repair requirements** **Qualify coating process and materials for use on SH-60 Helicopters**
Start/End Dates:	FY06 – FY08
Project Costs:	$550k
	MANTECH Investment: $50k thru FY06
	Cost Share: $1,087k ESTCP $760k JSF $400k Army
Weapon System:	SH-60 Seahawk and H-60 Helicopters

Performing Activities:

iMAST ARL Penn State – Project Lead
ESTCP Team (ONR, Army Research Lab, NAVAIR, Sikorsky, JSF) – Co-Funding Sponsor
Sikorsky Aircraft – Project Technical Assistant
NADEP Cherry Point – Project Customer and Implementation Site
NAVAIR SH-60 Program – Project Stakeholder

Technical Achievements:

Performance requirements met for Al-5%Mg powder with low cost nitrogen as carrier gas
Due to availability, high purity Al powder has been selected for initial coating material

Gearbox sump (internal mating surface) has been coated with HP Al. Evaluation of coating is underway.

Implementation:

System:	**SH**-60 and H-60 Helicopters, other rotor wing aircraft
Site	Naval Aviation Depot Cherry Point, NC
Schedule:	FY07/08
Status:	Initial coating trials have been conducted ESTCP team meeting planned for Aug 2006 to establish JTP for technology implementation

Payoff:

Benefits Analysis/ROI: 2.7:1
Double the life of the transmission housings
Reduce the number of transmission housings that have to be removed from service
Reclaim 60% of the hardware that has been removed from service
Reduce risks to worker health and safety
Reduce environmental impact

Automated Rotorblade Stripping System


Automation Rotor Blade Paint Stripping System (ARBSS)

Project Number:	**A1014**
Performing Activity:	iMAST(REPTECH) / ARL Penn State NCMS/CTMA Team
Objective:	Develop, qualify, and build an Automated Rotor Blade Paint Stripping System for CH-53E rotor blades.
Start/End Dates:	FY04 – FY09
Project Costs:	$5.5M
MANTECH Cost:	$814K
Cost Share:	$4.7M total
Weapon System:	CH-53E Super Stallion Helicopter

Performing Activities:

REPTECH ARL Penn State – Initial Project Lead
NCMS/CTMA – Co-Funding Sponsor
Sikorsky Aircraft – Project Technical Assistant and Sponsor
General Lasertronics – Project Technical Assistant and Sponsor
FRC East (Cherry Point) – Project Customer
NAVAIRSYSCOM 4.0, 6.0 – Project Stakeholder
NUWCDIVKEYPORT – Project Customer & Participant

Technical Achievements (Oct-Dec 2008):

- The upgrades to the ARBSS emissions capture/control system were completed and successfully tested in October 2008. There is now confidence that the system will function using the vacuum system provided by FRC East.
- Funding was provided by NCMS/CTMA to refurbish the failing lasers donated as cost-share to the project. This will ensure best possible system is installed at FRC East in mid-2009.
- Visited FRC Southwest (North Island) with NAVAIR Reptech Working Group representative in order to broaden application of the ARBSS technology.

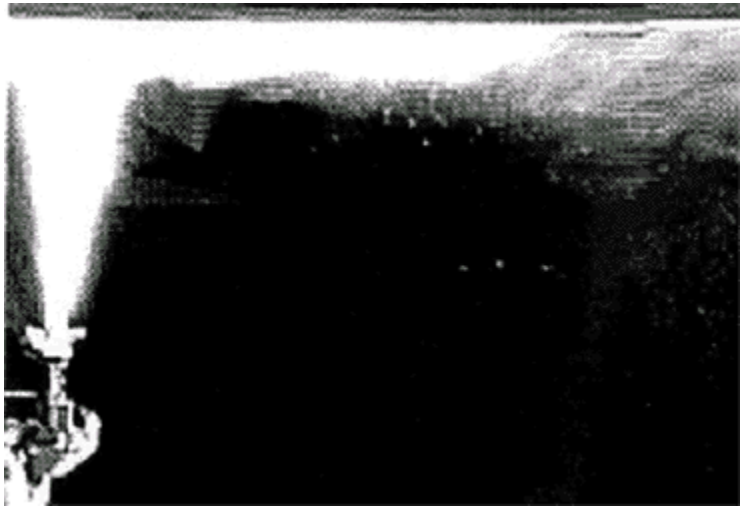
Implementation:

System:	CH-53E Super Stallion Helicopter, other rotor wing aircraft
Site	FRC Cherry Point, NC
Schedule:	FY09/FY10 CPP Purchase
Status:	Demo system complete. Final testing and debugging prior to installation is ongoing.

Payoff:

- Benefits Analysis/ROI: 2.2:1
- Reduce rotor blade stripping cost by 50% or more.
- Technology will benefit refurbishment of more than 900 blades each year at NADEP Cherry Point
- Potential implementation at Sikorsky
- Reduce rotor blade stripping time by 66% or more.
- Reduced process emissions compared to conventional manual hand sanding
- Reduced risks to worker health and safety
- Reduced environmental impact

High Efficiency Paint Spray Gun Development



Airless Paint Spray creates overspray (gray, top right) and contributes to material waste and environmental issues

Project Number: **S2176**
Title: **High Transfer Efficiency Paint Spray Gun Development**
Performing Activity: iMAST / ARL Penn State
Objective: Develop a commercial paint spray capable of achieving 95% transfer efficiency.
Start/End Dates: Jan 07 – Mar 08
Project Costs: $180K
MANTECH Investment: $180K
Cost Share: $0K
Weapon System: CV, CVN

Performing Activities:
- iMAST / ARL Penn State – Project lead
- NAVSEA 04 – Stakeholder
- NAVAIR – Stakeholder
- Marine Corps Logistics Base Albany – Stakeholder
- Puget Sound Naval Shipyard – Technical Assistant
- NAVSEA 05M - PM Office
- Spray Systems Inc. – Industrial partner

- **Technical Achievements:**
- Project funding received 23 February 2007
- 1st Prototype Complete

Implementation:

System: All surface and sub-surface ships, wheeled and tracked vehicles and DoD facilities
Site: Puget Sound Naval Shipyard
Schedule: 1st prototype will be tested 1 February 2008.
Status: On schedule. No technical or other issues at this time.

Payoff: $300,000 per year cost avoidance for a single medium-sized shipyard. The cost of overspray to the US shipbuilding industry is estimated at $50 million annually