NAVAIR Corrosion Program
Naval Aviation Enterprise
Materials, Coatings and Corrosion

Status Brief

August 17, 2011 Air Force Corrosion Conference

Frederick Lancaster AIR 4.3.4 Materials Engineering

OUTLINE

- Background – Cost of Corrosion/Impact
  - Naval Aviation Enterprise
- Drivers & Challenges
- Next Gen Materials
- Technology & Application Areas
- Efforts
- Summary

MATERIALS ENGINEERING

A FULL SPECTRUM APPROACH - S&T, ACQUISITION AND SUSTAINMENT TECHNOLOGIES FULLY INTEGRATED FOR ALL AEROSPACE SYSTEMS:

- AIR VEHICLES
- PROPULSION
- WEAPON SYSTEMS
- AVIONICS & SENSORS
- AIRCRAFT LAUNCH & RECOVERY EQUIPMENT
- SUPPORT EQUIPMENT

MATERIALS S & T

- 6.1 - 6.4
- SBIR and ILIR
- Manufacturing Technology
- Environmental Programs
- Technology Transfer
  - Metals and Ceramics
  - Propulsion Materials
  - Corrosion Technology
    - Materials Protection
  - Advanced Polymers and Composites
  - NDI
  - Functional materials

ACQUISITION SUPPORT/ RISK ASSESSMENT

- Requirements Definition
- Source Selection
- Design Reviews (PDR/CDR..)
- Materials & Process Specifications/CDRLs
- Design Allowables
- Performance Monitor
- M&P Certification
- Flight Clearance
- Technology Transition
- Repair Development/ Analysis

IN-SERVICE ENGINEERING/PRODUCTION SUPPORT

- FRC/ISSC Engineering Support
- Corrosion Prevention & Control
- HAZMAT Minimization / Environmental Compliance
- Aircraft and Engine Maintenance/ Repair/Life Extension
- Engineering Investigations Failure Analysis
- Mishap Investigation
- Aging Aircraft Initiatives
- GS and T/M/S Manuals
- Fleet Bulletins &

Materials design decisions made during Phase 1 impact A/C maintenance costs years/decades later.

NAE: TODAY AND TOMORROW

Phase 1
New Aircraft

- Establish Corrosion Contract Language and Define Corrosion Performance Criteria
- Develop Standard Verification and Validation Criteria for Environmental Performance
- Promulgate Corrosion Prevention/Control Guidance/Policy
- Establish and Support Corrosion Prevention Action Teams
- Revitalize Corrosion S&T
- Incorporate Lessons Learned

Phase 3
Late Mature Stage

- Service Life Assessment and Service Life Extension
- Optimize Corrosion Prevention and Control Strategies to
- Minimize Fleet Maintenance Actions
- Implement New Repair Technologies
- Feed Lessons Back to Early Mature and New Aircraft

Corrosion Stages of Life

Phase 2
Early Mature Stage

- Optimize Corrosion Prevention and Control Strategies to Minimize Fleet Maintenance Actions
- Demonstrate, Validate and Implement New Technologies
- Conduct Validation and Verification Inspections for Unproved Materials
- Establish Improved Data Collection Methods
- Standardize Data Assessment Methods
- Feed Lessons Back to New Aircraft

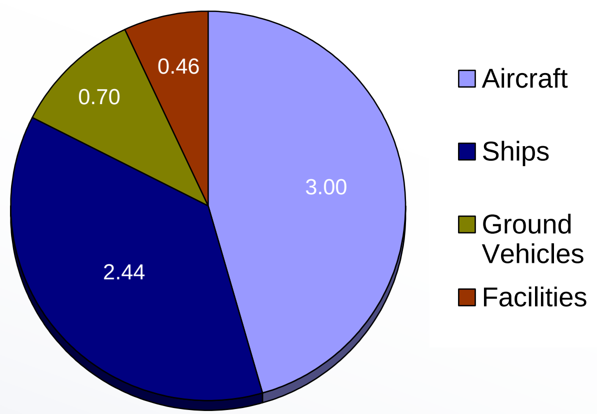
Phase 4
Final Life Stage

- Apply Advanced Inspection Techniques to Minimize Airframe and Component Disassembly
- Reduce Component Scrap Rate Through Emergent
- Remanufacturing Technologies
- Capture Lessons Learned and Fleet Data and Feed Back to Other Stages of Life

IMPACT OF CORROSION ON NAE/NAVY

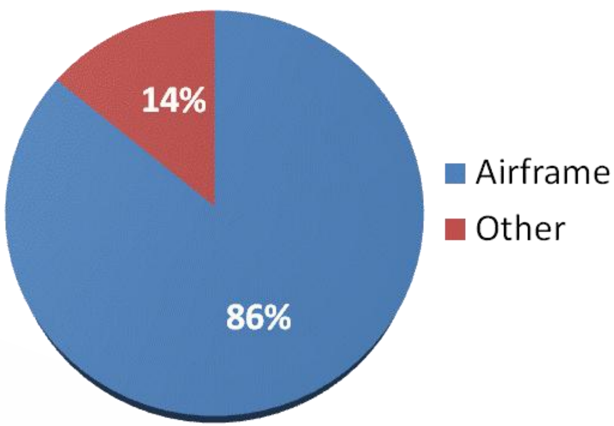
Total Annual Navy Cost, $6.6B

Corrosion Maintenance Costs, $B



NAE Annual Cost, $2.6B avg

$3B Corrosion Maintenance Cost

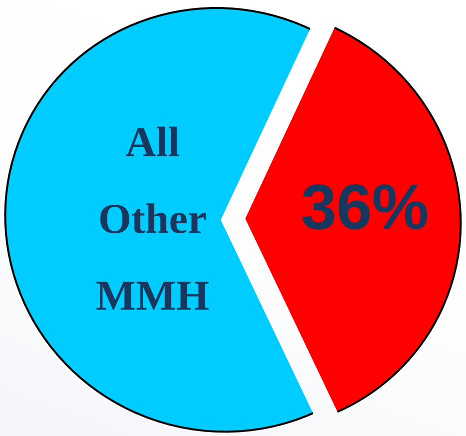


“death by a thousand cuts”

IMPACT ON COST & SAFETY

Maintenance Man-hours

Source: AIR-6.0/LCDR W. Conroy
(FY04 Study of 11 year Logistics Data)



Corrosion / Inspection MMH

(Ave 7.27 MMH/FH)

101,000,000(+) MMH expended against total corrosion/inspection effort during 1994-2004

Safety Impact

- **224 Safety incidents with corrosion as a causal factor**
- **227 A/C & 250 personnel Involved**
- **$238M Estimated Cost/Loss**

Landing Gear Stress Corrosion Cracking

- **Data Source: Navy Safety Center (FY93-FY03)**

NAE Annual Corrosion Cost ⇒ $2.6B avg

(2005 and 2006, 20010/LMI Cost of Corrosion Study, May 2008)

MAINTENANCE AND CORROSION COSTS

(from LMI Cost of Corrosion Report MEC70T3, May 2008, update May 2011)

Estimated annual depot costs

Node or sub-node	Description of corrosion cost node	Total aviation and engine maintenance cost (in millions)	Corrosion cost (in millions)	Corrosion cost as a percentage of total aviation and engine maintenance cost
A1	Navy organic depot direct labor	$649	$318	48.9%
A2	Marine Corps organic depot direct labor	$292	$172	58.8%
A3	Navy commercial depot labor	$308	$154	49.8%
A4	Marine Corps commercial depot labor	$165	$79	47.9%
B1	Navy organic depot materials	$646	$256	39.7%
B2	Marine Corps organic depot materials	$232	$91	39.2%
B3	Navy commercial depot materials	$606	$248	40.9%
B4	Marine Corps commercial depot materials	$344	$140	40.6%
	Depot overhead	$127	$0	0%
	Depot total	$3,369	$1,458	43.3%

Estimated annual field costs

Node or sub-node	Description of corrosion cost node	Total aviation and engine maintenance cost (in millions)	Corrosion cost (in millions)	Corrosion cost as a percentage of total aviation and engine maintenance cost
C1	Navy organic field-level direct labor	$3,197	$974	30.5%
C2	Marine Corps organic field-level direct labor	$920	$212	23.0%
C3	Navy commercial field-level labor	$176	$50	28.5%
C4	Marine Corps commercial field-level labor	$97	$23	24.0%
D1	Navy organic field-level materials	$689	$121	17.6%
D2	Marine Corps organic field-level materials	$324	$51	15.7%
D3	Navy commercial field-level materials	$56	$7	13.1%
D4	Marine Corps commercial field-level materials	$30	$5	16.5%
	Field-level overhead	$358	$0	0%
	Field-level total	$5,847	$1,443	24.7%
E	Labor of non-maintenance aviation operators	$88	$35	39.8%
F	Priority 2 and 3	$3	$3	N/A
G	Purchase cards	$16	$16	N/A
	Outside normal reporting total	$107	$54	N/A
	Total-all costs	$9,323	$2,955	31.7%

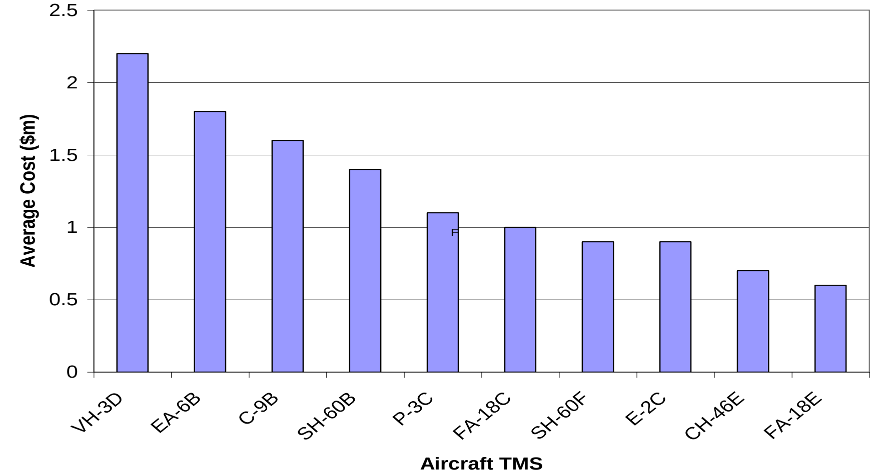
TMS Cost Rank/Combined

No.	TEC	TMS	Corrosion cost per item (in millions)	Per-item corrosion cost rank	Total corrosion cost (in millions)	Total corrosion cost rank	Combined Rank	
1	AAED	EA-6B	$1.7	2	$193.8	3	5	Navy retiring
2	AHZA	SH-60B	$1.4	4	$202.3	2	6	retiring
3	AMAF	FA-18C	$1.0	7	$382.3	1	8	
4	APBD	P-3C	$1.1	6	$179.7	4	10	
5	AHZB	SH-60F	$0.9	10	$63.9	9	19	retiring
6	AHRH	CH-46E	$0.7	15	$148.6	5	20	retiring
7	AMAH	FA-18E	$0.6	18	$68.8	6	24	
8	ACZB	C-9B	$1.6	3	$26.9	21	24	
9	AEBC	E-2C	$0.9	13	$58.0	12	25	
10	AHCS	VH-3D	$2.1	1	$23.6	24	25	retiring
11	AFXD	F-5N	$1.3	5	$25.1	22	27	
12	AHXD	CH-53E	$0.4	24	$65.8	7	31	
13	AHXJ	MH-53E	$0.9	12	$27.9	19	31	
14	ACWA	C-2A	$0.8	14	$27.9	18	32	
15	AHZN	MH-60S	$0.5	19	$46.7	14	33	
16	ACMC	C-130T	$0.9	9	$19.0	26	35	
17	AMAG	FA-18D	$0.4	26	$59.5	10	36	
18	ASBE	S-3B	$0.6	17	$27.3	20	37	retired
19	AFWE	F-14D	$0.9	11	$18.4	27	38	retired
20	AMAJ	FA-18F	$0.4	27	$58.5	11	38	

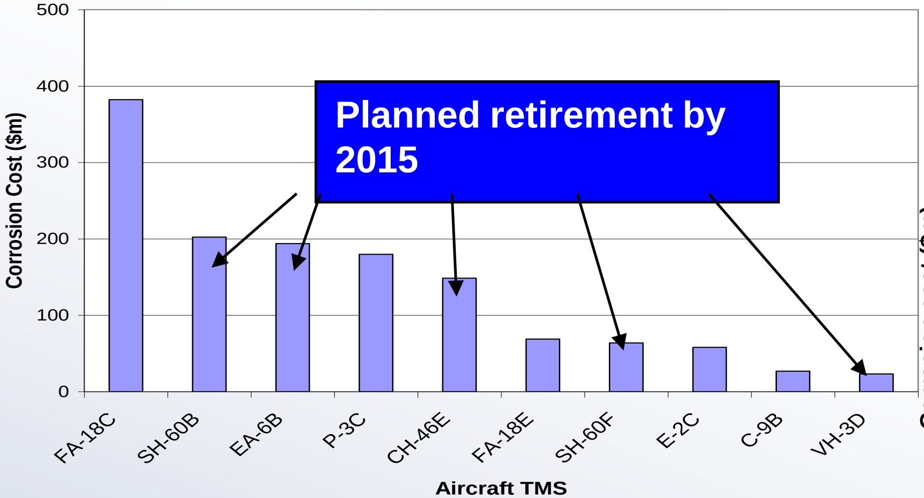
CORROSION COST

Factors: type of aircraft, # in inventory, age

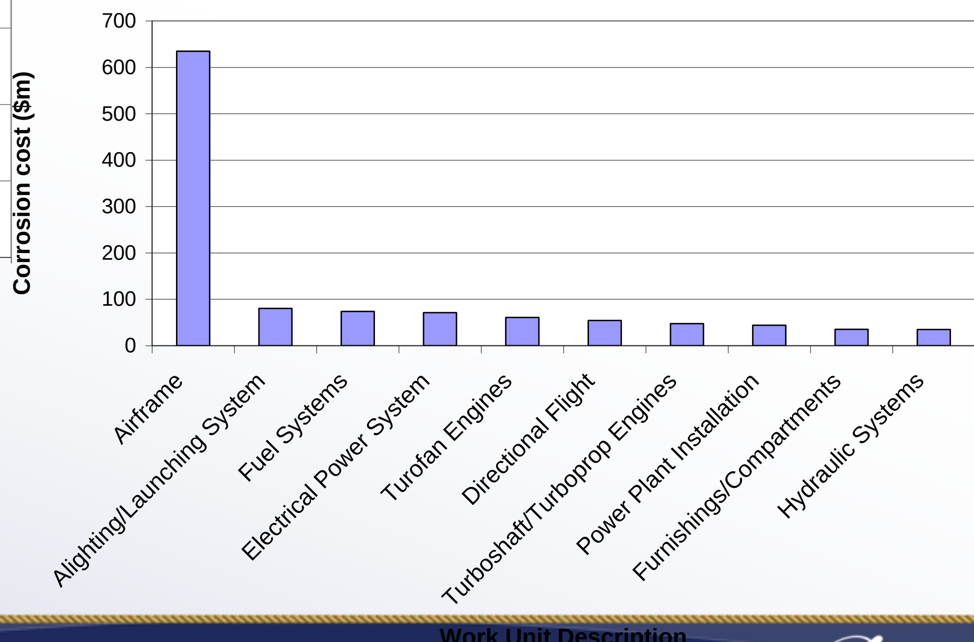
Location: Airframe corrosion ~7X greater than any other cost



Average cost per airframe



Total cost per aircraft type

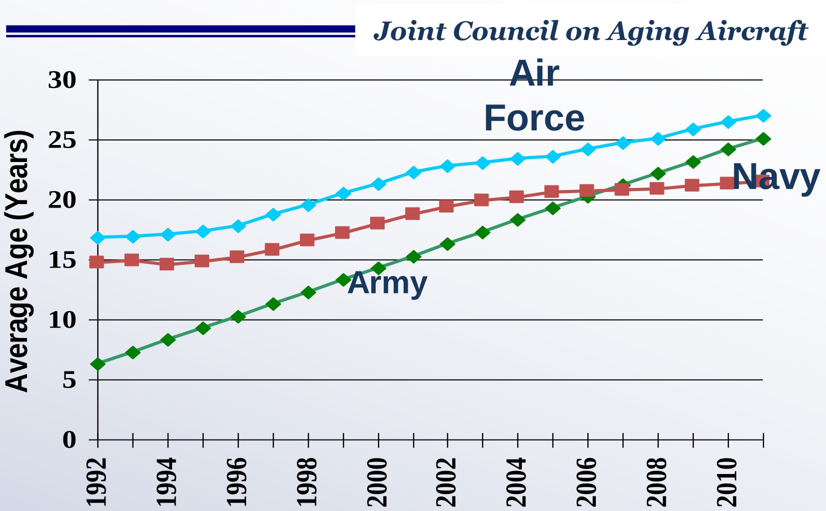


NAVAIR

CORROSION ISSUES

Current

- Aircraft Age and Material Condition
- Corrosion Data Integrity
- Reduced Fleet Corrosion Emphasis
- Reduced Training/CBT
- Unauthorized Material Usage



Future

- Corrosion Resistance lacking in Design
- Increased use of Dissimilar Materials
- PBL/incentive lags current platforms
- OEM knowledge of operational and maintenance environment
- Reactive vs Proactive approach

Overall

- Corrosion is an NAE-wide Concern
- No Baseline Corrosion Assessment
- Environmental Compliance
- Lack of Corrosion Metrics
- Cross-functional Corrosion Team

NAE CORROSION EFFORTS

- Congressional Mandate to address annual $22B DoD cost
  - Revised Policy and Regulations to emphasize corrosion
    - Focus areas – Acquistion/Design, Current Readiness, Sustainment

- NAE BOD sponsors Corrosion Prevention Team (CPT)
  - Air Board Maintenance & Supply Chain Management
    - Multi-competency, multi-disciplinary
  - Concept: Improve Airframe Material Condition Through Systematic Corrosion Abatement Strategies
  - Goals – Achieve Optimal Aircraft Readiness
    - Reduce Total RFT Gap To < 5%
    - Reduce RFT Gap Of Each TMS by 20%

Goal 1: Cost-wise Aircraft RFT Entitlement

Goal Team 1A:	CWRIIP
Goal Team 1B:	Component Reliability
Goal Team 1C:	Corrosion Control

Future Readiness

Acquire — Sustain — Retire

Future Readiness Team
Focused on Solutions in Acquisition so that Current Problems are Eliminated 20 Years from Now

Current: F/A-18E/F, EA-18G, V-22, H-60R/S, UH-1Y/AH-1Z

Next 10+ Years: P-8A, F-35B/C, MQ-8B, H-53K, BAMS, E-2D, STUAS, FA-XX, EP-X

DRIVERS

Performance –
- Reduced weight, Increased capability/range, Survivability

Durability –
- Improved structural strength, More damage resistant

Environmental –
- Green Technology, Regulatory compliance

Availability –
- Longer service life, Improved readiness, Decreased maintenance

DRIVERS

Performance

– Increased carbon fiber composites, more dissimilar materials/galvanic corrosion, increased conductive materials

Reliability

– More complex designs, No corrosion or environmental effects accounted for in maintenance planning

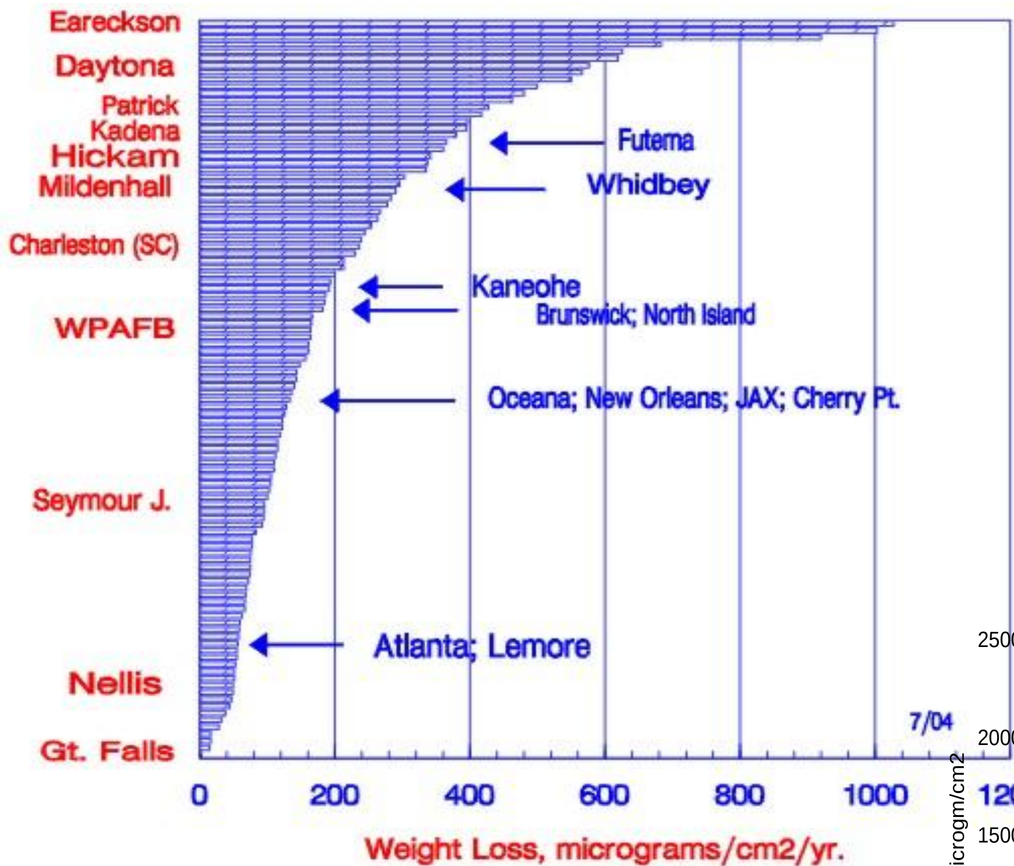
Environmental

– Focus solely on ESOH reduced robustness of protective materials and coatings

Availability

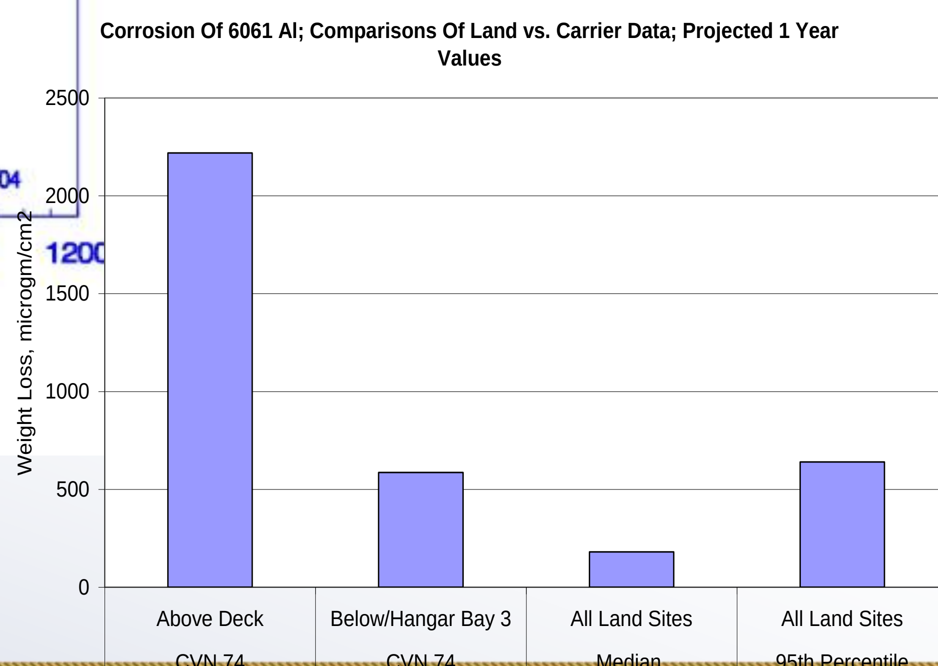
– Supply of exotic and more expensive materials, turn around time and cost of repairs

OPERATIONAL ENVIRONMENT



Navy/Marine Aviation and Air Force Land Sites

Carrier Exposure Rack on CVN 74



APPROACH

- **Change the aircraft design paradigm**
  - Increase corrosion resistance and maintainability of future acquisitions; enable corrosion resistant designs
- **Facilitate mission life prediction**
  - Increase current operational readiness, reduce lifecycle costs, and reduce logistics footprint
  - Increase future readiness of current platforms
  - Incorporate Affordability into design and construction phase
- **Galvanic Management of aircraft has never been done**
  - With the tools available today, aircraft are primarily designed for performance and structural response
  - Corrosion is an after-thought that is dealt with later in the lifecycle of the aircraft

NEXT GEN MATERIALS

- Life-of-Platform, Universal Coating and Corrosion Control Systems
  - Coatings for multi-material systems / Coatings & Maintenance Free Systems
    - Increased surface tolerance
    - Adaptive response to substrate
    - Elimination of environmental impact
- Predictive Corrosion Behavior & Design Integration
  - Rapid Recovery & Represervation
  - Reliable Corrosion Behavior & Design Integration
- Corrosion Resistance-by-Design for Materials & Systems
  - Durable Structural Materials
  - Integrated Corrosion Control - Engineering & Design Tools
  - Integrated corrosion control & functional coatings or systems

NEXT GEN MATERIALS

Corrosion controls systems which respond to wide dynamic ranges of operating environments

- Tools for Monitoring, Detection & Prognostics
- Self-healing & Self-assessing Systems
- Total Asset Management & Logistics

Corrosion Resistant Design & Standardized Technical Criteria & Data

- Complete Corrosion Engineering Circular in 2009
- Enhance Corrosion Action Teams
- Revise Acquisition Specifications – MIL-STD-7179A, MIL-S-5002, MIL-HDBK-1250

(ie paperwork)

NEXT GEN MATERIALS

Technology & Application Areas

- Disruptive Technologies
  - Galvanic modeling, simulation, and validation of corrosion designs
  - Carbon fiber composites with reduced effective cathode area
  - Galvanically tuned alloys for protection of high-strength steels
  - Benign conductive coatings and sealants
  - Universal sacrificial paint/coatings

Eliminate high-corrosion maintenance cost drivers for fleet

- Reduce a major portion of labor required to maintain airframes
- Improve airframe reliability fusing advanced mold line coatings
- Support CNAF-endorsed NAE Corrosion Prevention Team actions
- Extend service life of Navy aircraft beyond original design.
- All solutions fit into future platforms, i.e. F/A-XX

DEVELOPMENTAL NEEDS

- Coatings: Cr^{6+} is under pressure from government/DoD and commercial organizations – Aerospace is last "hold-out" for Cr^{6+} use in protective coatings
  - Navy and Marine Corps operating requirement is most challenging
    - Alternatives acceptable for automotive, commercial aviation, land-based DoD are typically not good enough
    - Simulation of operating environment a challenge for RDT&E and acquisition/design trade studies
- Basic understanding of corrosion protection mechanisms for qualified and emerging non-chromated primers
  - "Standard" chemically inhibited epoxies
    - Proprietary, not well understood inhibitors
  - Metal pigmented epoxies and polyurethanes
    - New galvanic/magnesium pigmented primers have different, poorly understood failure mechanisms
    - Accelerated testing yields coating rupturing and tunneling through coupons
    - Beach exposure yields rapid loss of coating, presumably due to high self-corrosion rate

DEVELOPMENTAL NEEDS

- Primers with improved flexibility, high adhesion and easy removal
- Primers and topcoats with improved processing characteristics
  - Extended or zero pot life, Reduced or zero cure time
- Reduce or eliminate VOCs/HAPs/TRI chemicals from current coating systems
  - Goal of zero emissions from the entire finishing system
- Basic understanding of the effect of coating inhibitors on stress-corrosion cracking and corrosion fatigue
- Extreme weathering topcoats, including correlation between pigments and ultimate topcoat life
  - Gloss red, orange, and blue (trainer)
  - Flat greys (tactical)

DEVELOPMENTAL NEEDS

Accelerated tests with better correlation to beach and ship operating environment

- Correlation of accelerated corrosion test results with results of natural, beach front exposure results
  - "Cherry Picking" alloys and accelerated tests leads to strong false positives and negatives

Re-vitalizing working relationship with key S&T areas

- Growing links with universities
  - Projects, People
- Working to Establish ONR Corrosion S&T Funding
  - Corrosion Innovative Naval Prototype Proposal for "Durable Aircraft"

EFFORTS

Develop galvanic management technologies and engineered systems that eliminate fleet maintenance and reduce life-cycle corrosion cost of aircraft

Major Focus Areas

- **Surface Potential Modeling & Simulation**
- **Tests for Prototyping Corrosion**
- **Engineered Interfaces**

Navy Science & Technology Guidance

- **Seapower**
- **Naval Aviation Enterprise S&T Strategy**
  - **2009 NAVAL S&T Plan ONR**

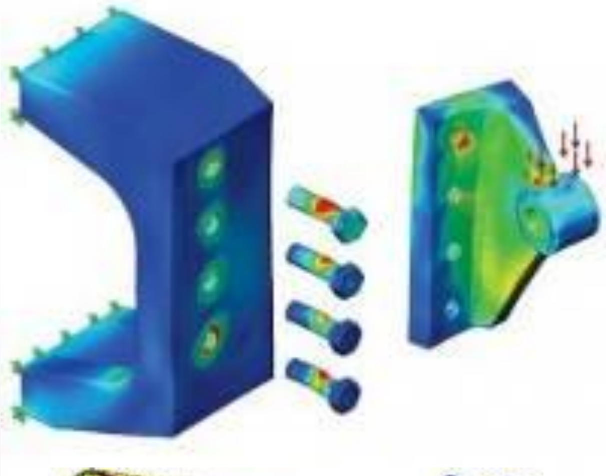
Requires a Radical Shift in Design Philosophy

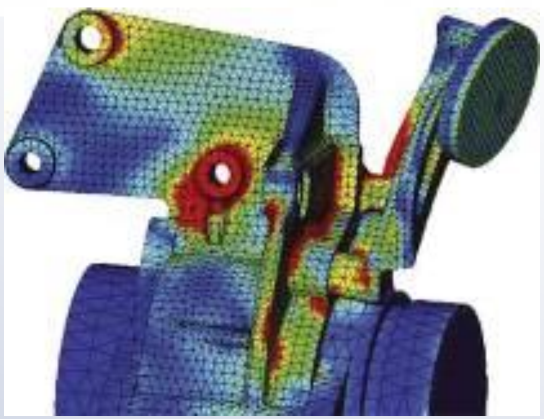
Technology solutions will focus on highest cost drivers by platform and need

Corrosion is an after-thought that is dealt with later in the lifecycle of the aircraft

MIXED-MODE SURFACE POTENTIAL MODELING

Vision of Multi-Mode Corrosion Tool: Mapping Galvanic Corrosion Rates





$$\Delta V = \Delta V^o - \frac{RT}{nF}\ln\frac{[M_1^{n+}]}{[M_2^{m+}]}$$

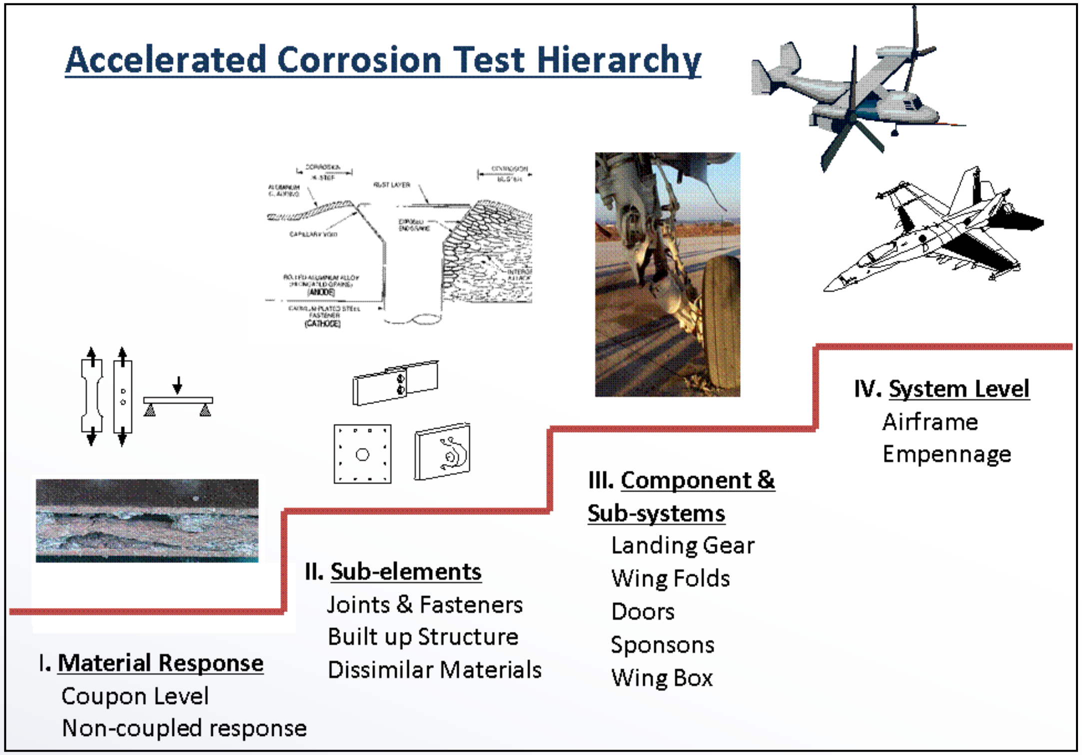
Description: Innovative technologies that enable the modeling, simulation and validation of galvanic stress

Proposed Investment

- computer model of mixed corrosion modes
- validation process for model
- simulator for assembled component designs

- **Electric Potential Drives Corrosion**
- **Factors**
  - **EM Environment**
  - **Weather / Op Environment**
  - **Dissimilar Materials**
  - **Design/Operational Stress**
  - **Coatings/Inhibitors**
  - **Materials Loss/Degradation**
  - **Crevices/occluded spaces**
  - **Corrosion product buildup-induced stresses**

ADVANCED PROTOTYPING



- Government- Industry Accepted
- Validate Corrosion Response
- Realistic and Reliable
- Enables credible design AoA
- Enforceable Contract Language
- Design validation via DT
- Provides Answers
    - How much will it cost/save?
    - How long will it last?
    - What is the ROI?

Innovative test technologies that enable prototyping and risk reduction for airframe corrosion performance at sea

Proposed Investment:

- test and validation process
- prototyping standard
- advanced trade study method

ENGINEERED INTERFACES

Technology solutions will focus on highest cost drivers by platform and need – multiple possible solutions

Description: **Develop new technologies that reduce or isolate galvanic potential between materials used on airframe**

Proposed Investment:

- **Carbon fiber composites with reduced cathode area and less noble open circuit potential**
- **Multi-compatible fasteners and conductive coatings/sealants**
- **Galvanically tuned protective coatings**

Products

Pretreatments

Cleaners

Dust Containment

Canopy/Windscreen Restoration & Maintenance

CPC's

Products

- Ready to use MIL-PRF-85570 Type II
- MIL-PRF-85570 Type 1 in Aerosol & Pre-Moistened Wipes
- Micro-mesh Cloths for Canopy & Optics Cleaning
- MIL-DTL-81706 Type II Non-Chrome Pretreatment Applicator Pen
- MIL-PRF-29608 Class L CPC Electrical Contact Cleaner
- Non-Chrome pretreatments
- Advanced performing topcoats
- Cold Spray Metallization
- Hot-melt glue sticks for non-structural adhesives
- Waterless Aircraft Wash
- MIL-PRF-32295 Types I & II (PD-680 alternatives)
- Helicopter engine wash diverter
- Portable dust containment
- Selectively strippable midcoats
- Non-chrome primers
- Canopy & windscreen restoration products

SUMMARY

- Corrosion is a significant cost to the Navy
  - NAVAIR's total annual budget is ~$40B; annual corrosion cost is estimated at $3.0B
- The Naval Aviation Enterprise Corrosion
  - Prevention Team is attacking corrosion problem in all phases of aircraft life cycle
- Solutions lie in the areas of leadership,
  - training, policy, basing, materials, design, and documentation
- Key Outcome: Balanced approach to reduce impact of corrosion on NAE
- *Materials design and selection decisions made during concept and production impact A/C maintenance costs years/decades later*

THANK YOU!