Third ARO Workshop on Smart Structures

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Hosted by:
Center for Intelligent Material Systems and Structures
Virginia Polytechnic Institute and State University

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Donaldson Brown Hotel and Conference Center ■ Blacksburg, Virginia
Active Controls / Smart Structures S&T Programs
for Army Aviation within ATCOM & ARL

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&
Dr. Robert Ormiston, ATCOM AeroFlightDynamics Directorate

Presented at the 3rd ARO Workshop on
Smart Structures, Blacksburg VA
Outline

- Why smart structures in Army Aviation
- Army Aviation S&T Planning
- Rotorcraft applications at ARL - Vehicle Structures Center & NASA Langley
- SBIR programs at AATD
- Rotorcraft applications at ATCOM - Aeroflightdynamics Directorate & NASA Ames
- Summary
Smart Structures in Army Aviation (Why & How)?

- Potential to meet RWV Aeromechanics Tech Effort Objectives for max blade loading, aerodynamic efficiency, vibratory loads, and acoustic radiation
  - Vibration Reduction:
    - Trailing edge ‘Elevons’; ‘Active Twist’
  - Noise Reduction:
    - BVI Noise Control- trailing edge flaps / blade twist
  - Performance Enhancement:
    - Surface ‘oscillatory blowing’ ; Leading edge deformation / multi-element airfoils
- Power and flexibility provides unique potential to tailor forces and control laws
- Technical Barriers include:
  - Mechanisms for altering blade shape: materials, mechanisms, & actuators
  - Smart materials with increased force and strain capability
  - Reduce undesirable vibratory blade response - Not affect desireable responses
  - Optimize structural design to include controller strategy at transient flight conditions with highly nonlinear phenomena:
    - Dynamic stall at boundaries of flight envelope
    - Rotor/Wake interaction - BVI acoustic interaction
- Posture technology to be able to support a 6.3 demonstrator (3rdGARD) and/or transfer directly to industry by 2001
# Army Aviation Technology Strategy

### System Capabilities

<table>
<thead>
<tr>
<th>Year</th>
<th>Prototype</th>
<th>EMD</th>
<th>RAH-66</th>
<th>EOC</th>
<th>Prod</th>
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<td>97</td>
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**AH-64D Longbow Apache**

### Versatility & Flexibility

- Rotorcraft Pilots Associate
- Multi-Sensor Aided Targeting-Air
- Radar Deception & Jamming
- Combined Arms C2

- Covert Nap of the Earth Flight
- AirLand Enhanced Recon & Targeting
- 3rd Gen Sensor Integration
- Low Cost Precision Kill
- Brilliant Weapons Int
- Non-Lethal Weapons
- Full-Spectrum Threat Protection

### Upgrades

- OH-58D
- UH-60
- AH-64
- CH-47
- RAH-66

### Versatility

- Adv Rotorcraft Transmission
- Rotary Wing Structures Technology

### Advanced Platform Technologies

- 3rd Gen Advanced Rotor Design

### Deployability

- Adv Rotorcraft Aeromech Tech

### Joint Rotorcraft

- Covert NOE Flight

### Sustainability

- On-Board Integrated Diagnostics System
- Navy Diagnostics Program

### CH-47 / Improved Cargo Helicopter

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The diagram illustrates the Army Aviation Technology Strategy focusing on system capabilities, versatility, equipment, weaponization & integration, upgrades, and sustainability. Key technologies and programs are highlighted, including advancements in rotorcraft technology and the development of improved cargo helicopters.
ARCAT
Advanced Rotorcraft Aeromechanics Technologies

- High Performance Rotor Aerodynamics
  - Optimized geometry
  - High-lift airfoils
  - Multi-element & oscillatory blowing
- Low Noise Concepts
  - Active blade aero-control
  - Reduced blade-vortex interaction
- Low Vibration Rotor
  - Optimized structural dynamics
  - Active blade aero-control
  - Increased inherent rotor lag damping
- Reduced Adverse Aero Forces
  - Rotor-fuselage interaction
  - Download
  - Yaw forces

Increase Efficiency, Reduce Drag
expand range/payload envelope
Reduce Vibration
reduce maintenance
Increase Inherent Rotor Lag Damping
reduction in flight safety parts

125 nmi
Current UH-60

UH-60 with ARCAT Technologies
170 nmi

Rotary Wing TDA 2000

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<tr>
<th>Payoff</th>
<th>TDA</th>
<th>ARCAT Contribution</th>
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<tbody>
<tr>
<td>Range</td>
<td>+55%</td>
<td>+36%</td>
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<tr>
<td>Payload</td>
<td>+36%</td>
<td>+23%</td>
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<tr>
<td>Cruise Speed</td>
<td>+8%</td>
<td>+5%</td>
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<tr>
<td>Maneuverability / Agility</td>
<td>+30%</td>
<td>+6%</td>
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3rd GARD
3rd Generation Advanced Rotor Demonstration Program

AH-64 Mission Profile @ TOGW=15,200 lbs
- 8 Hellfire missiles
- 20 min HOGE Target
- 30 min Fuel Reserve
- Cruise Velocity @ Best Range, 4000 ft, 95°F

Low Vibration Rotor
- Optimized structural dynamics
- Active blade aero-control

Inertial Tuning
Aerodynamic Tailoring
Structural Tuning
Adaptive Controls

Low Noise Concepts
- Active blade aero-control
- Reduced Blade Vortex Interaction

High Performance Rotor Aerodynamics
- Optimized geometry
- High-lift airfoils
- Multi-element & oscillatory blowing

AH-64 with 3rdGARD Rotor
200 nmi

AH-64 with Current Rotor
125 nmi

Rotary Wing TDA 2005

<table>
<thead>
<tr>
<th>Payoff</th>
<th>TDA</th>
<th>3rdGARD Contribution</th>
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</thead>
<tbody>
<tr>
<td>Range</td>
<td>+136%</td>
<td>+61%</td>
</tr>
<tr>
<td>Cruise Speed</td>
<td>+15%</td>
<td>+6%</td>
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<tr>
<td>Maneuverability</td>
<td>+50%</td>
<td>+10%</td>
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<tr>
<td>Agility</td>
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<td></td>
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<tr>
<td>Acoustic Footprint</td>
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Rotorcraft Aeromechanics Program Strategy

- Aeromechanics Steering Committee (AVRDEC/VTC) planning - -

- Plan developed to focus on DTAP Aeromechanics technical objectives

- DOD RWV Aeromechanics S&T Program Plan completed - 16 Dec 1996

- Aeromechanics Key Thrust Focus

- Major Milestone Roadmaps
  - Demos leading to 3rdGARD

- Major Milestone Narrative Descriptions

- Integrated Army, NASA, University (ARO/COE), Industry (NRTC/RITA, IR&D) Programs
Langley (Army/NASA) Smart Structures Applications for Rotorcraft

- Multi-Element Airfoil Technology
- Active Twist Rotor (ATR) Concept
Multi-Element Airfoil Technology

Rationale
- Forward-slotted airfoils demonstrated major improvements in max lift
- Potential to substantially improve helicopter perf and maneuverability
- MSES and MCARFA codes accurate for attached flow
- Rotor performance test showed mixed results

Payoffs
- Increase $C_l/\sigma$ max, delay retreating blade stall
- Candidate for HLR Demo

Plans
- CFD application to address low $C_l$ drag rise
  - Baseline Airfoil Analysis
  - Rotorcraft Performance Payoff Analysis
  - Slotted Airfoil Design and Analysis, Airfoil geometry
- Wind tunnel test confirmation

Drag Rise at Low $C_l$

Favorable Drag Divergence
Active Twist Rotor (ATR) Concept

- Piezoelectric control of blade twisting for:
  - reducing vibrations; noise
  - improving performance
  - suppressing stall
  - enhancing stability

- High blade twist possible using piezoelectric fiber composites (PFC); inter-digitated poling (IDE)
Active Twist Rotor Research

Analysis of ATR frequency response for 1-g hovering flight; 0P-16P sinusoidal electric field

- Analytical efforts:
  - in-house aeroelasticity code for preliminary design; control studies (ARL-Langley Research Center)
  - modified version of CAMRAD II (can apply periodic twisting couples)
- Experimental efforts:
  - 1/5 scale ATR model blade under joint development with MIT
Aviation Applied Technology Directorate
SBIR Programs

- Smart, Compact Packages for Vibration Control
- On-Blade Synthetic Active Control for Vibration and Acoustics Reduction
- High Power Density Magetostrictive Reaction Mass Actuator
- High Bandwidth Rotating to Non-rotating Data Transfer and Power Transmission
SMART, COMPACT PACKAGES FOR VIBRATION CONTROL

OBJECTIVE: Package piezo actuators and sensors, drive electronics, active control electronics into turnkey device for active structural damping.

APPROACH: ACX Proprietary packaging technology combined with advances in surface mount electronics.

RESULTS: Compact (2x6x1/8”), light weight (1.5 oz) SmartPack™, which has achieved 20x increase in modal damping and 15dB decrease in radiated noise on flat plate.

CONTRACTOR: Active Control eXperts, Inc.

AATD POC: Eric Robeson (757) 878-2975
On-Blade Synthetic Active Control for Vibration and Acoustics Reduction

**OBJECTIVE:** Develop a practical method of implementing active arrays of piezoelectric actuators in the rotating frame of the helicopter main rotor to implement active blade control.

**APPROACH:** Design an electronics drive system which will be practically implemented through the use of innovative concepts (synthetic impedance, microcompact CMOS high-speed switching and network controllers) to overcome technology barriers of bulky electronics, large energy consumption and high system losses.

**RESULTS:** An implementation of multimodal structural control using totally decoupled synthetic networks was demonstrated, which proved the feasibility of a self governing, semi-autonomous, active adaptive system capable of addressing multiple mission needs. This concept is under going further development for implementation in the wind tunnel.

**CONTRACTOR:** EMF Industries, Inc.

**AATD POC:** Donald Merkley (757) 878-0139
High Power Density Magnetostrictive Reaction Mass Actuator  
(Active Noise Cancellation for Helicopter Main Transmissions)

**Problem Statement:**

- Gearbox Vibrations primary driver of rotorcraft internal noise
- Weight of current active noise cancellation actuators excessive

**Approach:**

- Develop a very high power density actuator for use in active noise cancellation systems
- Utilize TERFENOL-D material to drive reaction mass
- Design actuator to produce 30 lbs force at 800 HZ with weight less than 0.8 lbs

**Results:**

- Actuator tested that exceeded requirements
- 10-15 dB reduction in cabin noise

**Contractor:** SatCon Technology Corp

**AATD POC:** Clay Ames  
(757) 878-0040
High Bandwidth Rotating to Non-rotating Data Transfer and Power Transmission

**OBJECTIVE:** Develop an affordable system for reliably transmitting data and power to/from the rotating main rotor and the fixed fuselage of a helicopter.

**Tetra Corporation**

**APPROACH:** Magnetically Coupled Rotating Interface (MCRI) couples a high frequency carrier which contains coded analog and digital signals with no physical contact.

**RESULTS:** Prototype bench testing completed. On-going effort to optimize, fabricate and whirl test both concepts.

**AATD POC:** Eric Robeson (757) 878-2975

**Saddleback Aerospace**

**APPROACH:** Rotor Optical Data Interface (RODI) utilizes optical emitters and detectors for data transfer and separate a device for power transmission.
Ames (Army/NASA) Smart Structures Applications for Rotorcraft
Smart Structures Active Elevon Rotor

Rationale
- Reduce loads & vib - provide practical, effective IBC at source; integrate IBC & flight control.
- Reduced BVI noise
- Performance - Improve load distribution, reduce stall
- Enhanced Maneuverability - Reduce load limits; increase thrust capability

7.5' Dia ADM Rotor, Hover Testing, Open Loop

Effect of RPM on Elevon Motion
5 Hz Elevon Motion

Effect of RPM on Elevon Effectiveness
5 Hz Elevon Motion
Smart Structures Active Elevon Rotor

Status
- Hover testing successful
- Forward flight testing underway

Plans
- Closed loop ADM testing
- Initiate 12-Ft AER Demo for loads, vib, noise objectives

Hover Test Data

Flap Bending Dynamic Response

Blade Torsion Dynamic Response

7.5' Dia ADM Rotor, Forward Flight Testing, Open Loop Control
Summary