Third ARO Workshop on Smart Structures

Sponsored by:

U.S. Army Research Office
Research Triangle Park, North Carolina

Hosted by:

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

August 27–29, 1997

Donaldson Brown Hotel and Conference Center ■ Blacksburg, Virginia

Active Controls / Smart Structures S&T Programs for Army Aviation within ATCOM & ARL

Danny R. Hoad, ARL Vehicle Structures Technology Center
&
Dr. Robert Ormiston, ATCOM AeroFlightDynamics Directorate

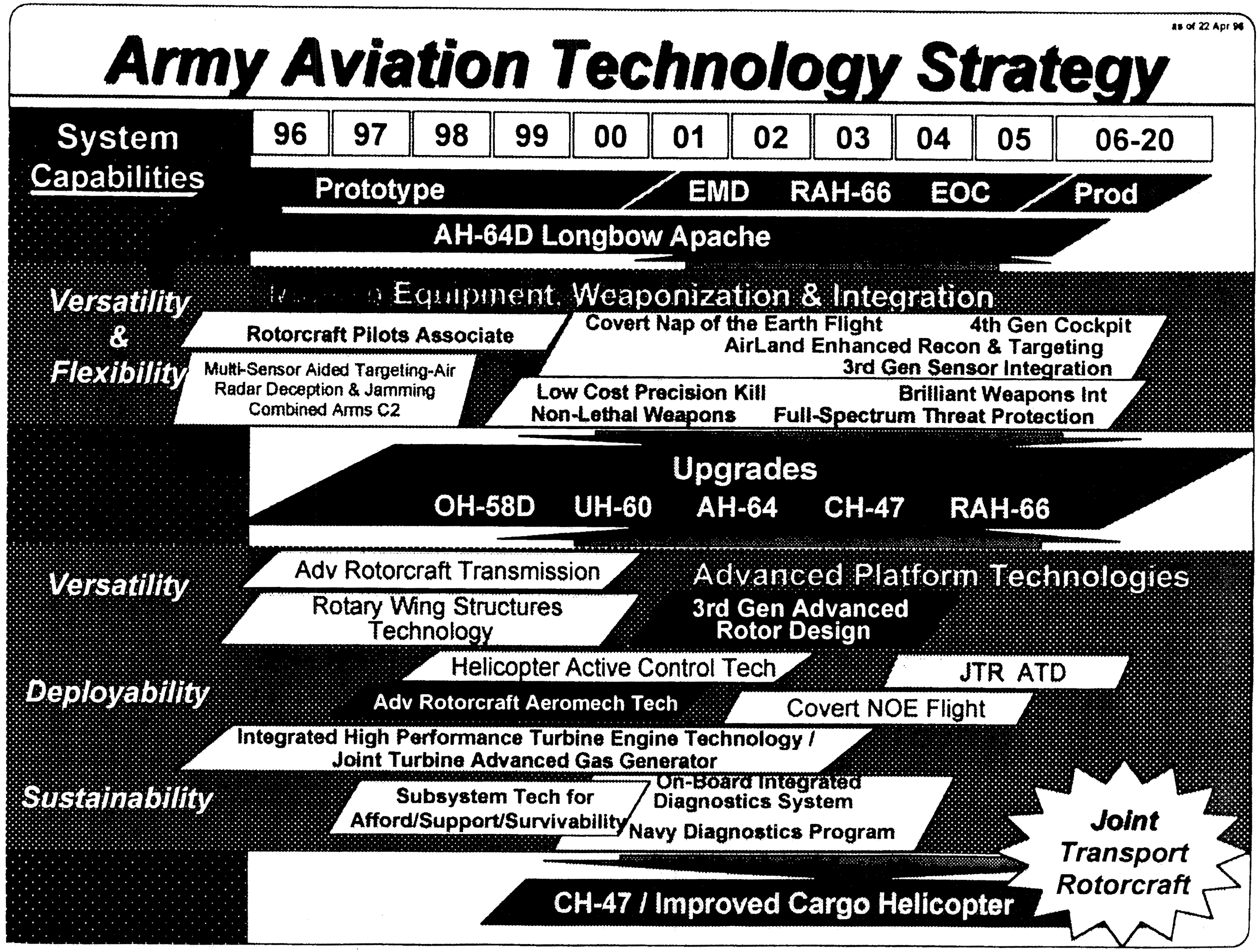
Presented at the 3rd ARO Workshop on
Smart Structures, Blacksburg VA

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**


as of 22 Apr 96
Army Aviation Technology Strategy
System Capabilities
96
97
98
99
00
01
02
03
04
05
06-20
Prototype
EMD
RAH-66
EOC
Prod
AH-64D Longbow Apache
Versatility & Flexibility
Equipment, Weaponization & Integration
Rotorcraft Pilots Associate
Covert Nap of the Earth Flight
4th Gen Cockpit
AirLand Enhanced Recon & Targeting
3rd Gen Sensor Integration
Multi-Sensor Aided Targeting-Air
Radar Deception & Jamming
Combined Arms C2
Low Cost Precision Kill
Non-Lethal Weapons
Brilliant Weapons Int
Full-Spectrum Threat Protection
Upgrades
OH-58D
UH-60
AH-64
CH-47
RAH-66
Versatility
Adv Rotorcraft Transmission
Advanced Platform Technologies
Rotary Wing Structures Technology
3rd Gen Advanced Rotor Design
Deployability
Helicopter Active Control Tech
JTR ATD
Adv Rotorcraft Aeromech Tech
Covert NOE Flight
Integrated High Performance Turbine Engine Technology / Joint Turbine Advanced Gas Generator
Sustainability
Subsystem Tech for Afford/Support/Survivability
On-Board Integrated Diagnostics System
Navy Diagnostics Program
Joint Transport Rotorcraft
CH-47 / Improved Cargo Helicopter

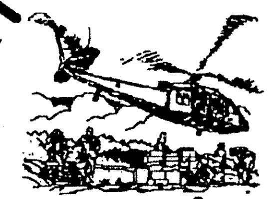
ARCAT
Advanced Rotorcraft Aeromechanics Technologies

- **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



170 nmi

UH-60 with ARCAT Technologies

Rotary Wing TDA 2000

Payoff	TDA	ARCAT Contribution
Range	+55%	+36%
-or-		
Payload	+36%	+23%
Cruise Speed	+8%	+5%
Maneuverability / Agility	+30%	+6%

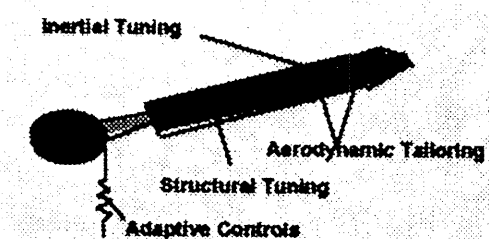
3rd GARD

3rd Generation Advanced Rotor Demonstration Program

AH-64 Mission Profile @ TOGW=15,200 lbs

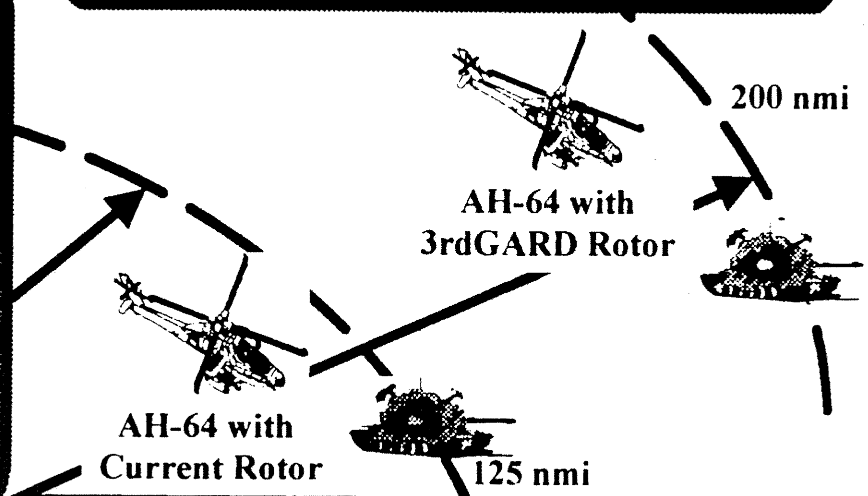
- 8 Hellfire missiles
- 325 Rounds
- 20 min HOGE Target
- 30 min Fuel Reserve
- Cruise Velocity @ Best Range, 4000 ft, 95° F

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



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

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



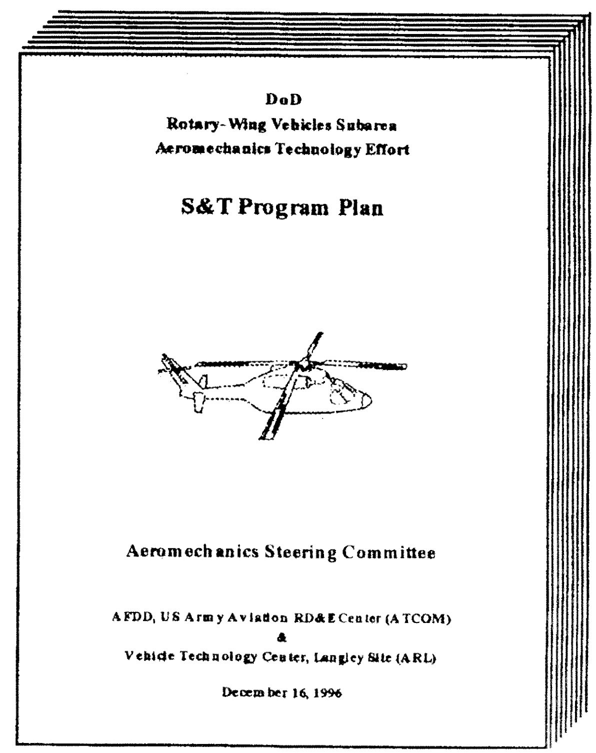
Rotary Wing TDA 2005

Payoff	TDA	3rdGARD Contribution
Range	+136%	+61%
Cruise Speed	+15%	+6%
Maneuverability / Agility	+50%	+10%
Acoustic Footprint		-50%

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


DoD
Rotary-Wing Vehicles Subarea
Aeromechanics Technology Effort

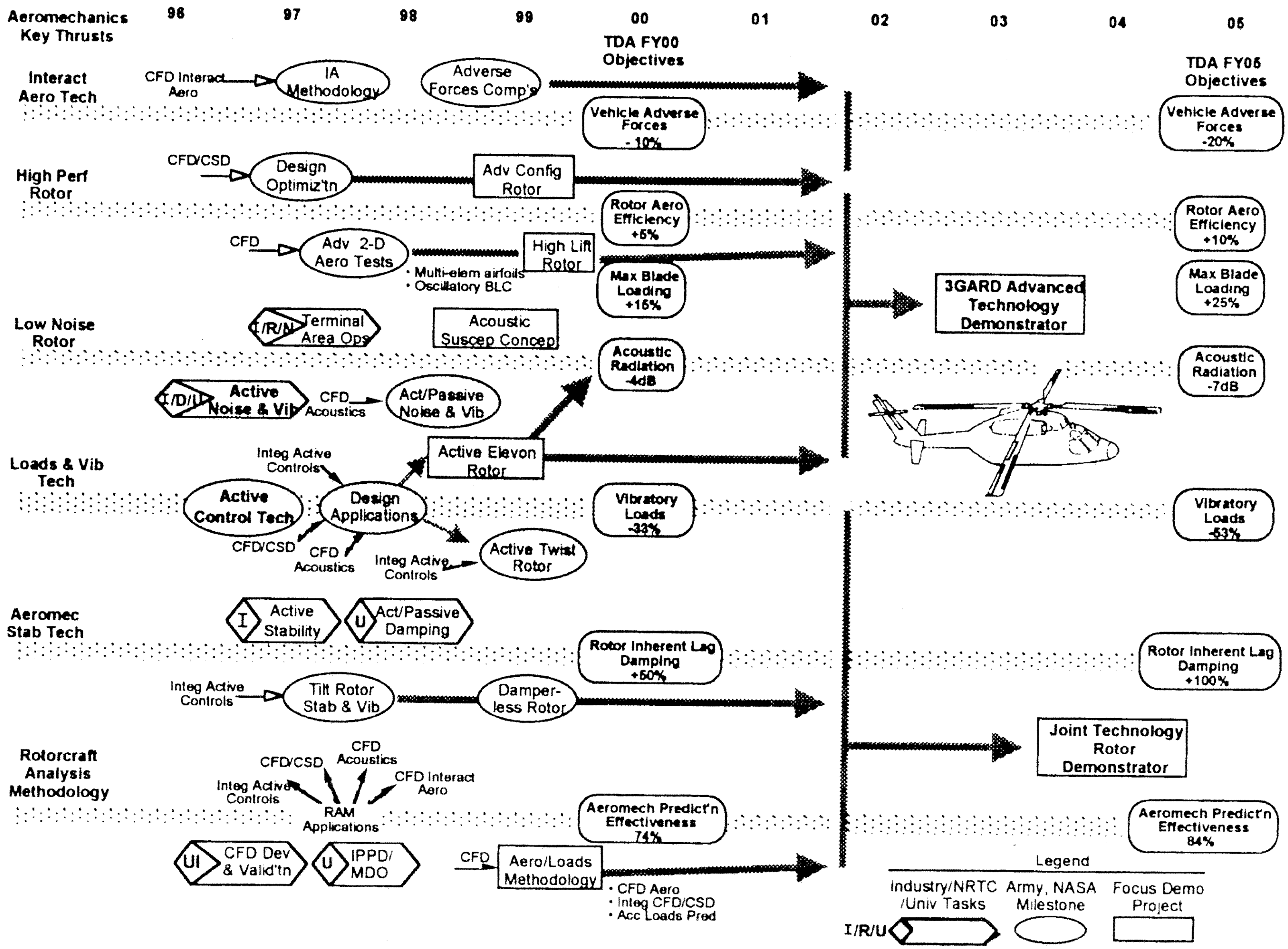
S&T Program Plan

Aeromechanics Steering Committee

AFDD, US Army Aviation RD&E Center (ATCOM)
&
Vehicle Technology Center, Langley Site (ARL)

December 16, 1996

Rotary Wing Vehicles
Aeromechanics Tech Effort Roadmap



Langley (Army/NASA) Smart Structures Applications for Rotorcraft

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

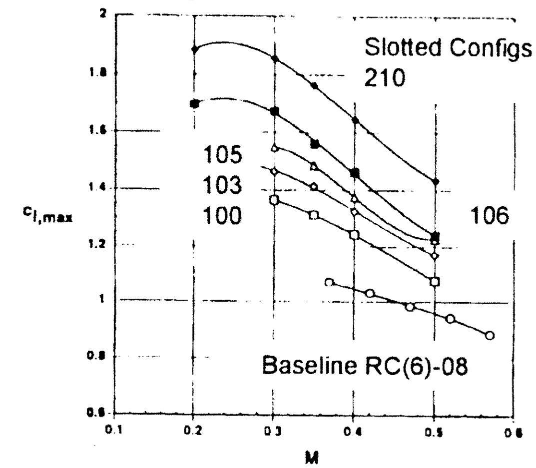
Multi-Element Airfoil Technology

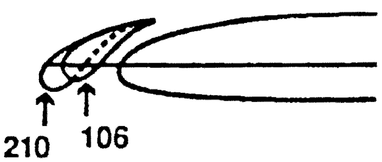
Rationale
- Forward-slotted airfoils demonstrated major improvements in max lift
- Potential to substantially improve helicopter perf and maneuverability
- MSES and MCARFA codes accurate for attached flow
- Rotor performance test showed mixed results

Payoffs
- Increase C_t/σ max, delay retreating blade stall
- Candidate for HLR Demo

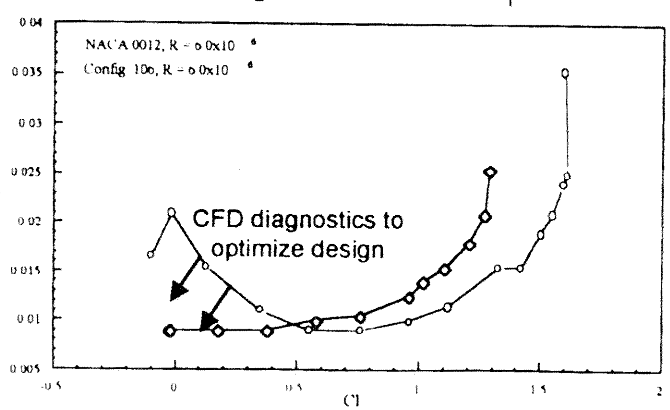
Plans
- CFD application to address low C_l drag rise
  - Baseline Airfoil Analysis
  - Rotorcraft Performance Payoff Analysis
  - Slotted Airfoil Design and Analysis, Airfoil geometry
- Wind tunnel test confirmation

Significant Lift Benefit

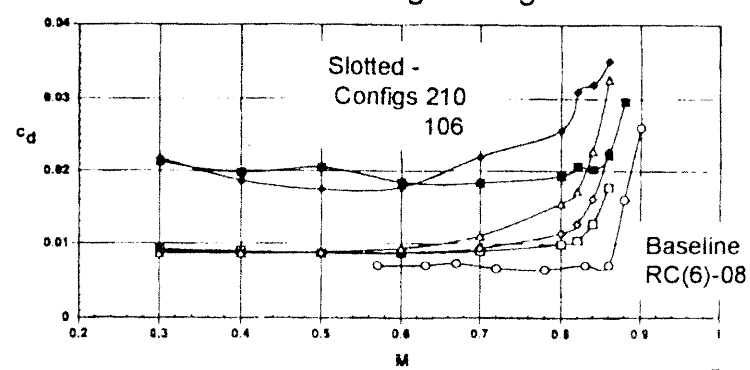




Drag Rise at Low C_l

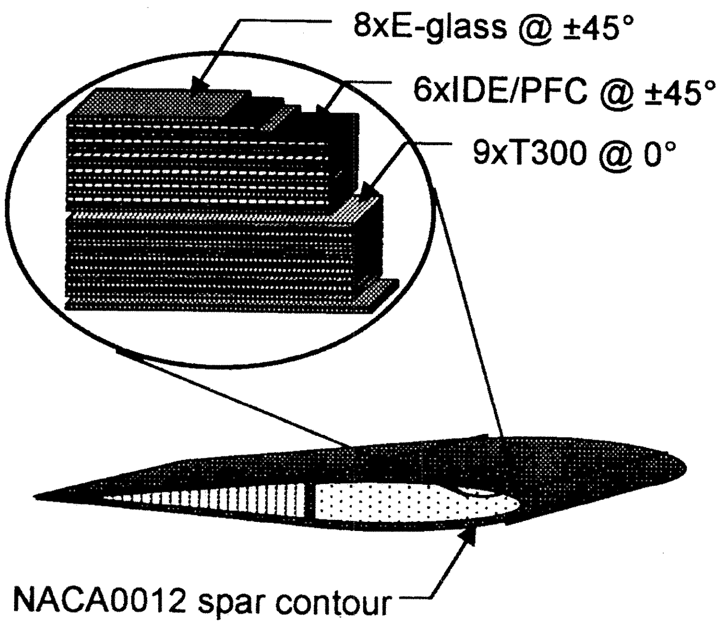


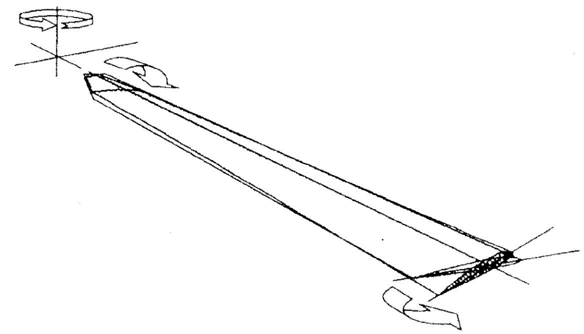
Favorable Drag Divergence



Active Twist Rotor (ATR) Concept

Conceptual ATR structure with embedded IDE/PFC laminae





- 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

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Creator:  MATLAB, The Mathworks, Inc
CreationDate:  02/13/97  12:06:00
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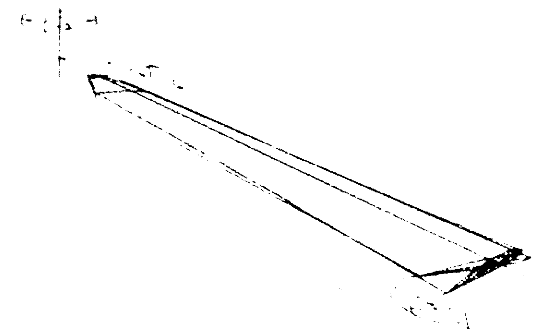


- Analytical efforts:
  - in-house aeroelasticity code for preliminary design; control studies (ARL-Langley Research Center)
  - modified version of CAMRAD II (can apply periodic twisting couples)
- Experimental efforts:
  - 1/5 scale ATR model blade under joint development with MIT

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

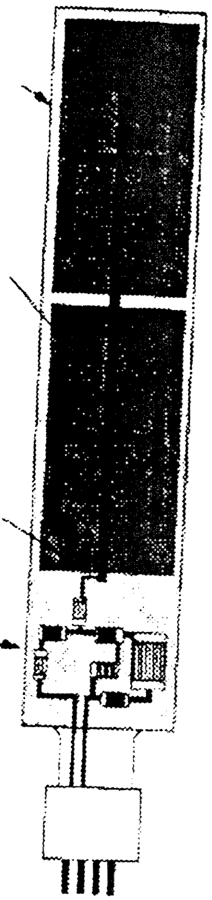
OBJECTIVE: Package piezo actuators and sensors, drive electronics, active control electronics into turnkey device for active structural damping.

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 Magetostrictive Reaction Mass Actuator

(Active Noise Cancellation for Helicopter Main Transmissions)

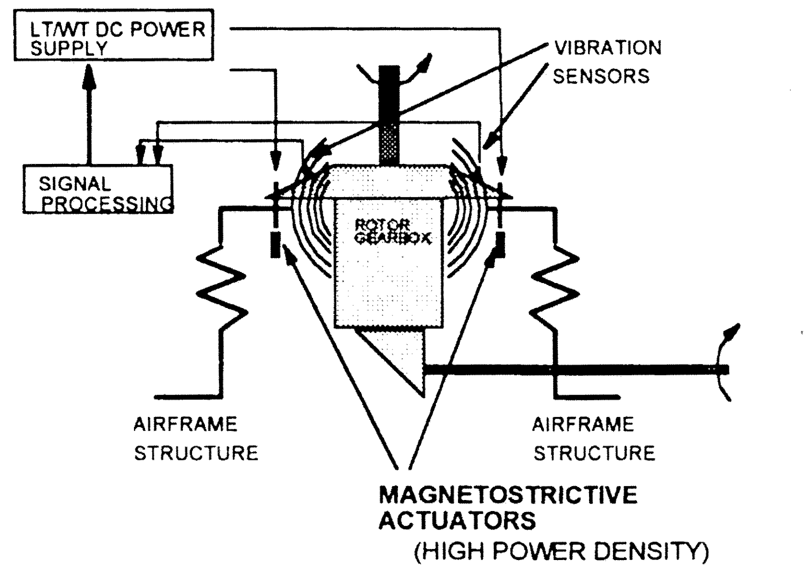
Problem Statement:
- Gearbox Vibrations primary driver of rotorcraft internal noise
- Weight of current active noise cancellation actuators excessive

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

Active Noise Cancellation System



AATD POC: Clay Ames
(757) 878-0040

c:/SATCONI/SATQUAD.PPT

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.

Saddleback Aerospace

APPROACH: Rotor Optical Data Interface (RODI) utilizes optical emitters and detectors for data transfer and separate a device for power transmission.

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

AATD POC: Eric Robeson (757) 878-2975

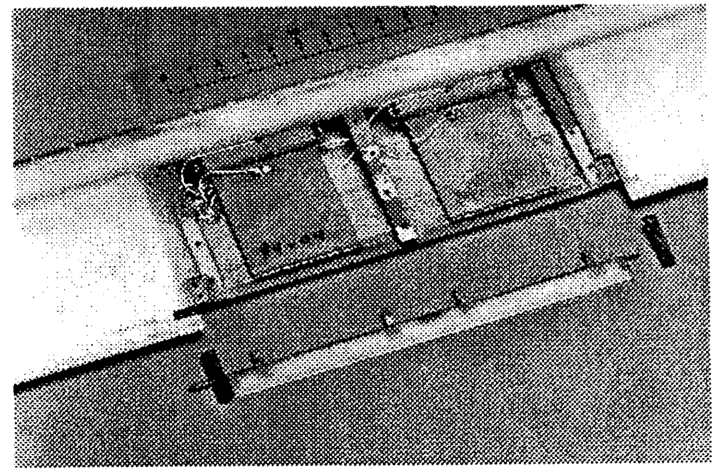
Ames (Army/NASA) Smart Structures Applications for Rotorcraft

Smart Structures Active Elevon Rotor

Rationale

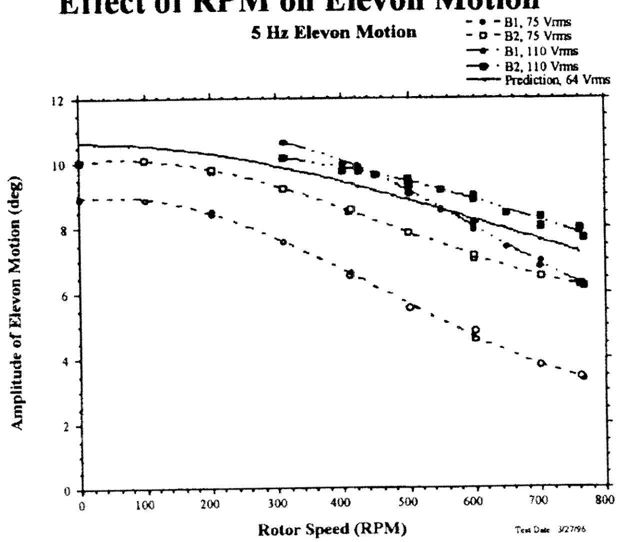
- Reduce loads & vib - provide practical, effective IBC at source; integrate IBC & flight control.
- Reduced BVI noise
- Performance - Improve load distribution, reduce stall
- Enhanced Maneuverability - Reduce load limits; increase thrust capability

Elevon and Piezoceramic Actuator

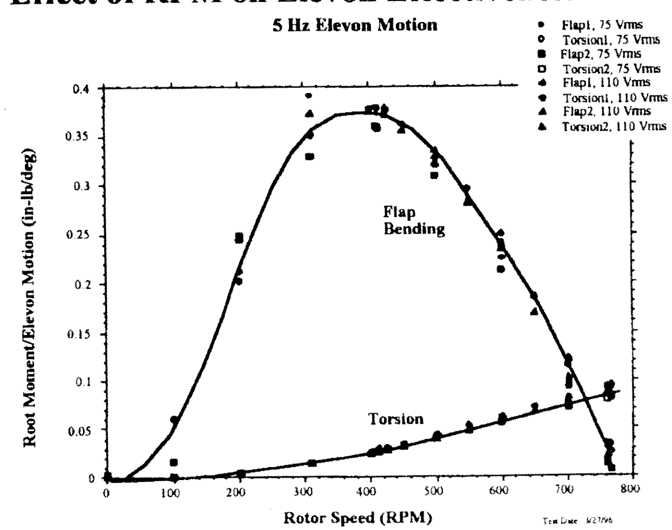


7.5' Dia ADM Rotor, Hover Testing, Open Loop

Effect of RPM on Elevon Motion



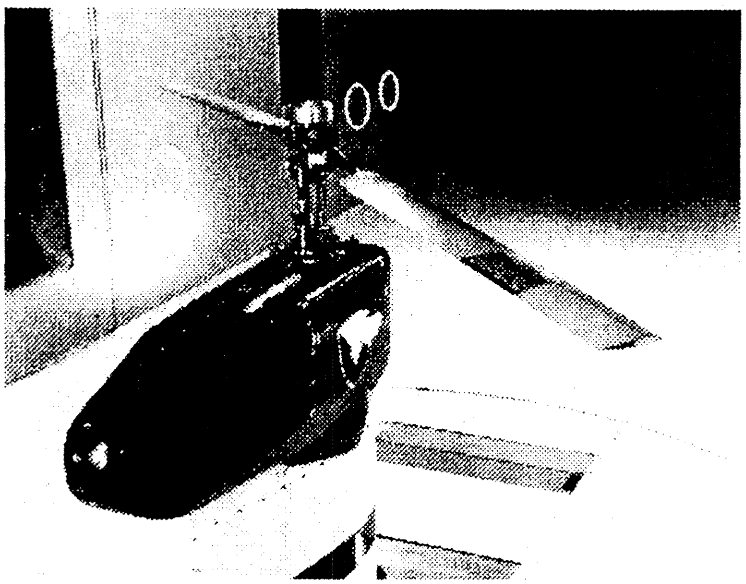
Effect of RPM on Elevon Effectiveness



Smart Structures Active Elevon Rotor

Status
- Hover testing successful
- Forward flight testing underway

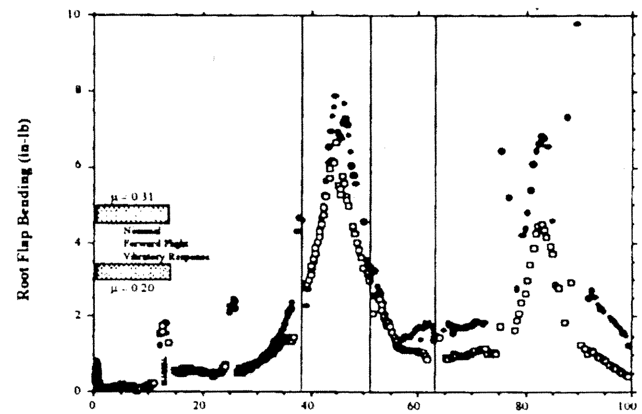
Plans
- Closed loop ADM testing
- Initiate 12-Ft AER Demo for loads, vib, noise objectives



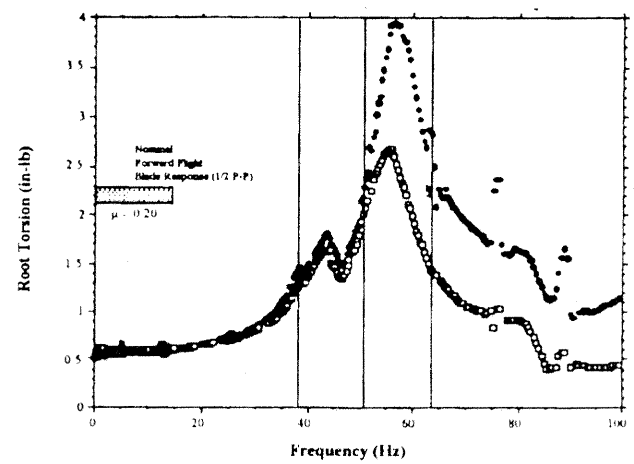
7.5' Dia ADM Rotor, Forward Flight Testing, Open Loop Control

Hover Test Data

Flap Bending Dynamic Response



Blade Torsion Dynamic Response



Summary