WELCOME!

Hybrid Insect MEMS Proposer ṡ Day

Amit Lal
Program Manager, *DARPA-MTO*
CSAC, MX, HERMIT, NGIMG

March 24, 2006

Agenda

8:00 – 9:00	**Registration/Continental Breakfast**
9:00 – 9:10	**Welcome/Introduction**, Dr. Amit Lal Schedule Goals of the workshop Distinguish between press and attendees
9:10 – 10:10	**HI-MEMS Program Overview**, Dr. Amit Lal 6.1 implications Rationale for program Possible Technical approaches Metrics policy MX policy
10:10 – 10:40	**Break, MEMS Exchange**
10:40 – 11:00	**Poster Session Introduction**, Proposers
11:00 – 1:00	**Poster Session / Lunch / Sidebars**
1:00 – 1:30	**Q & A**
1:30 – 3:00	**Proposer Presentations** (Can go longer depending on participant response)
3:00 – 3:30	**Closing Remarks**

Workshop Goals

- Goals of this workshop è
  - Learn about the HI-MEMS program
  - Exchange of information (intra and inter disciplinary)
  - Formation of teams
  - Introduce DARPA to new possibilities

New Program Manager in MTO

Amit Lal:

- Joined DARPA/MTO in October 2005
- Degrees: BSEE-1990: Caltech, Ph.D.-1996: UC Berkeley
- Professional Background:
  - Associate Professor, School of Electrical and Computer Engineering, Cornell University
  - Other Appointments:
    - Dept. of Bioengineering
    - Dept. of Biological Engineering
- Interests: MEMS, ultrasonics, radioactivity, bio-MEMS, ultra-low power circuit design

DARPA Mission

Department of Defense
DIRECTIVE

NUMBER 5134.10
February 17, 1995
Certified Current as of November 21, 2003

Incorporating Through Change 2, July 16, 2001
DA&M

SUBJECT: Defense Advanced Research Projects Agency (DARPA)

References: (a) Title 10, United States Code
(b) DoD Directive 5105.41, "Defense Advanced Research Projects Agency," January 25, 1989 (hereby canceled)
(c) Federal Acquisition Regulation, Subpart 2.1, April 1, 1984, supplemented by Defense FAR Supplement, Subpart 202.1
(d) DoD Directive 8910.1, "Management and Control of Information Requirements," June 11, 1993

1. PURPOSE

Under the authority vested in the Secretary of Defense by Section 113 of reference (a), this Directive establishes the DARPA as an agency of the Department of Defense with the responsibilities, functions, relationships, and authorities as prescribed herein; and replaces reference (b).

2. APPLICABILITY

This Directive applies to the Office of the Secretary of Defense, the Military Departments, the Chairman of the Joint Chiefs of Staff, the Combatant Commands, the Office of the Inspector General of the Department of Defense, the Defense Agencies, and the DoD Field Activities (hereafter referred to collectively as "the DoD Components").

1

The DARPA shall serve as the central research and development organization of the Department of Defense with a primary responsibility to maintain U.S. technological superiority over potential adversaries.

-- DoD Directive 5134.10
February, 18, 1995

DARPA Mission:

To develop, imaginative, innovative and often high-risk research ideas offering a significant technological impact that will go well beyond the normal evolutionary developmental approaches; and to pursue these ideas from the demonstration of technical feasibility through the development of prototype systems.

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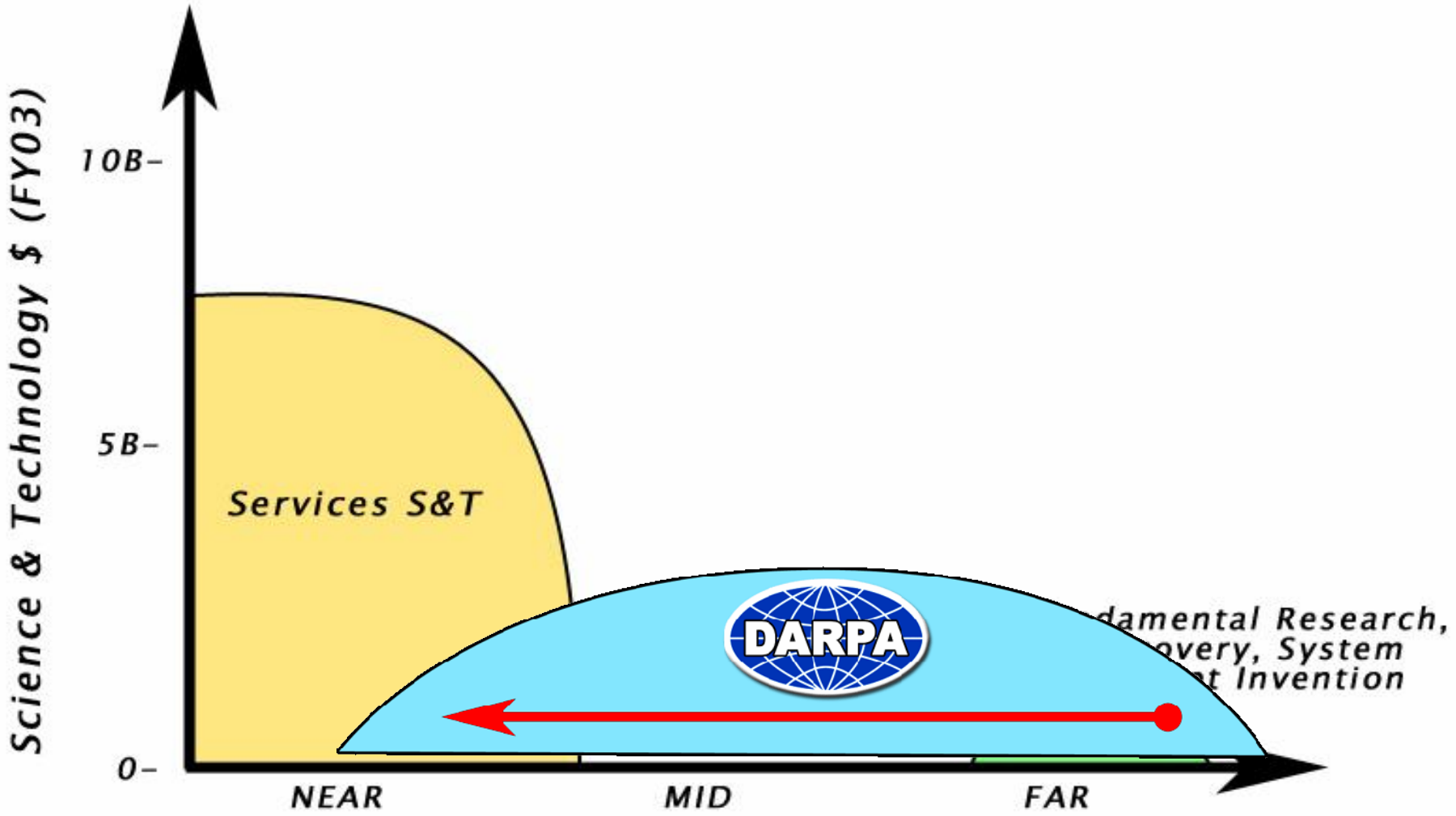
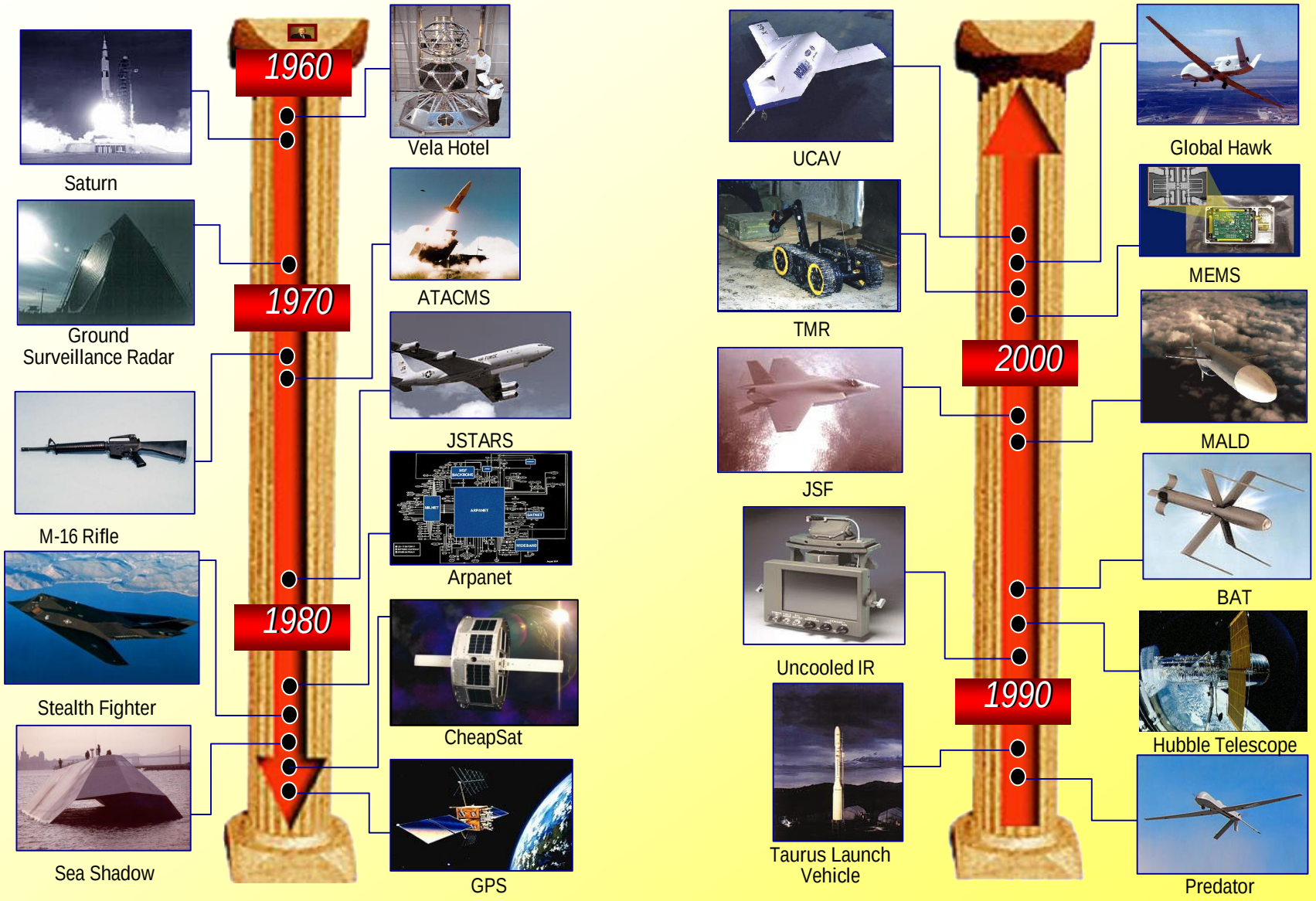
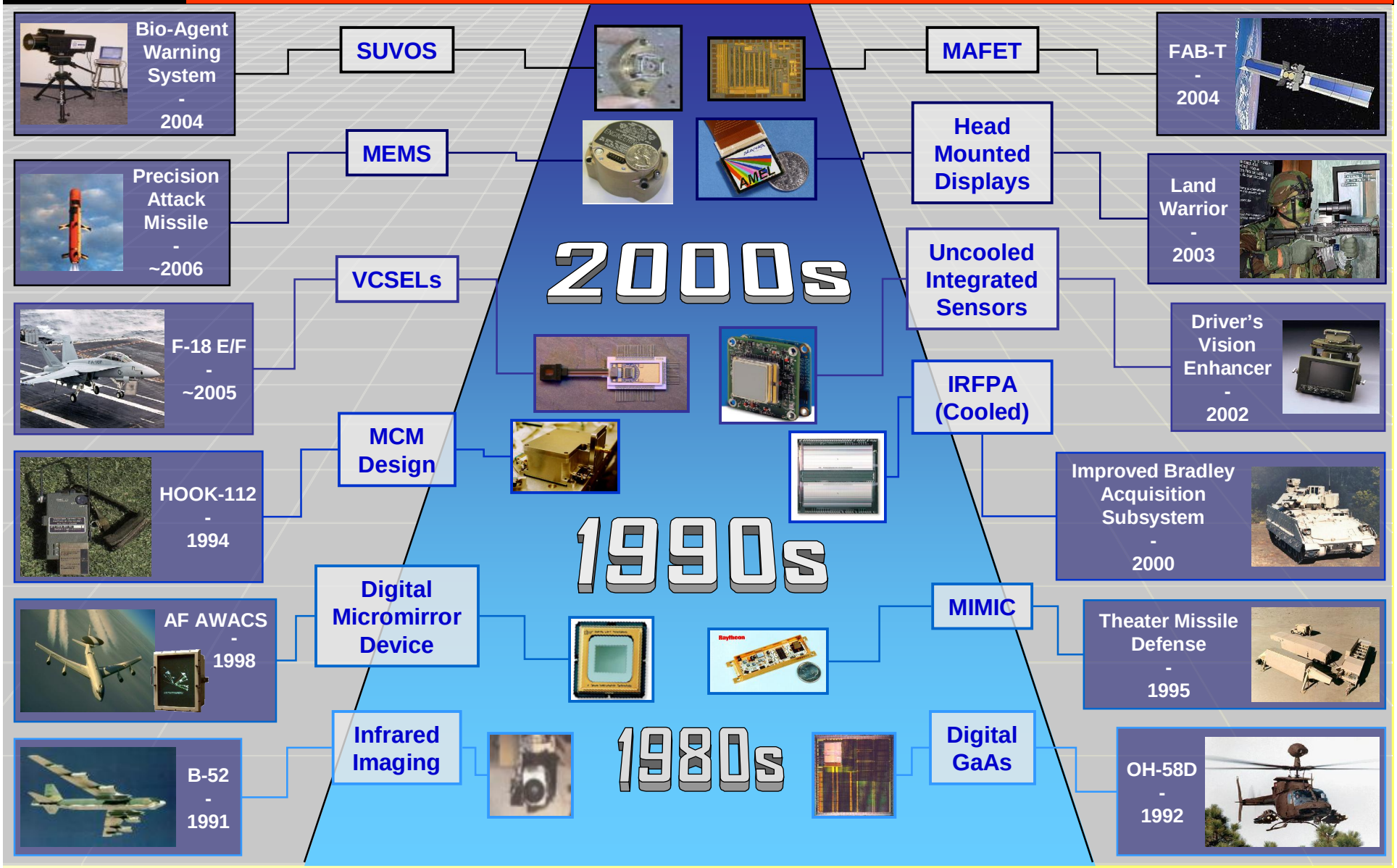
DARPA Role in Science and Technology



DARPA Accomplishments



Enabling System Capability



DARPA Organization

Director, Tony Tether
Deputy Director, Bob Leheny

Information Exploitation
Ted Bially
Bob Tenney/Bob Popp

- Sensors
- Exploitation Systems
- Command & Control

Tactical Technology
Stephen Welby
Gary Graham

- Air/Space/Land Platforms
- Unmanned Systems
- Space Operations
- Laser Systems
- Future Combat Systems
- Planning / Logistics

Special Projects
Joe Guerci
Brian Pierce

- Chem/Bio Def Systems
- Counter Underground Facilities
- Space Sensors/Structures
- Navigation/Sensors/ Signal Processing

Advanced Technology
Dave Honey
Larry Stotts

- Assured C3ISR
- Maritime
- Early Entry/Special Forces

Defense Sciences
Steven Wax
Brett Giroir

- Bio Warfare Defense Technologies
- Biology
- Materials & Devices
- Mathematics

Information Processing Technology
Charlie Holland
Barbara Yoon

- Cognitive Systems
- Computational - Perception
- Representation & Reasoning
- Learning
- Natural Communication

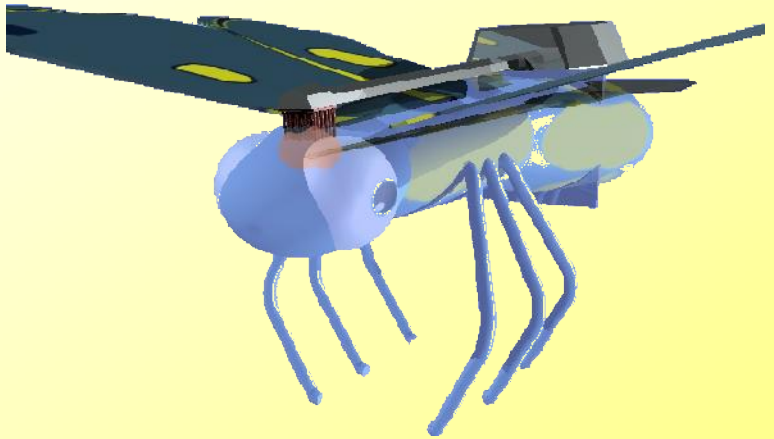
MicrosystemsTechnology
John Zolper
Dean Collins

- Electronics
- Optoelectronics
- MEMS
- Combined Microsystems

HIMS Vision and Objectives

VISION

Create technology to reliably integrate microsystems payloads on insects to enable insect cyborgs



OBJECTIVES

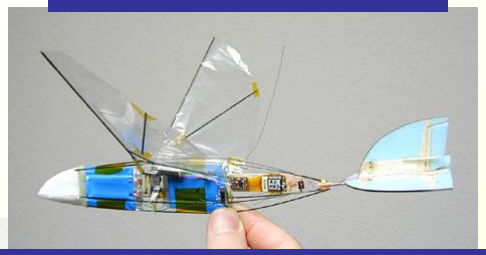
- Develop technology to enable highly coupled electro mechanical interfaces to insect anatomy
- Demonstrate MEMS platforms for electronic locomotion control, power harvesting from insect, and eliminate extraneous biological functions

HI-MEMS basics

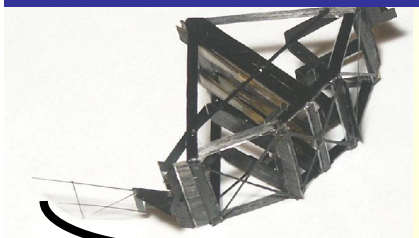
- Hi-MEMS is a 6.1 Basic Research program
  - The program will explore how MEMS can be integrated with insects
  - Enhance DOD, provide fundamental understanding of engineered biology, and provide seeds for future programs
  - All universities, companies, and government labs are welcomed to submit proposals

Background

Caltech flyer



UC Berkeley Flyer



WASP-DARPA, 200 grams, 12-inch wing span, 1-2 hr fly time

Nano - Air Vehicle Program

- ***20-30 minute mission***
- ***7-cm wingspan***
- ***Controlled hover and landing***

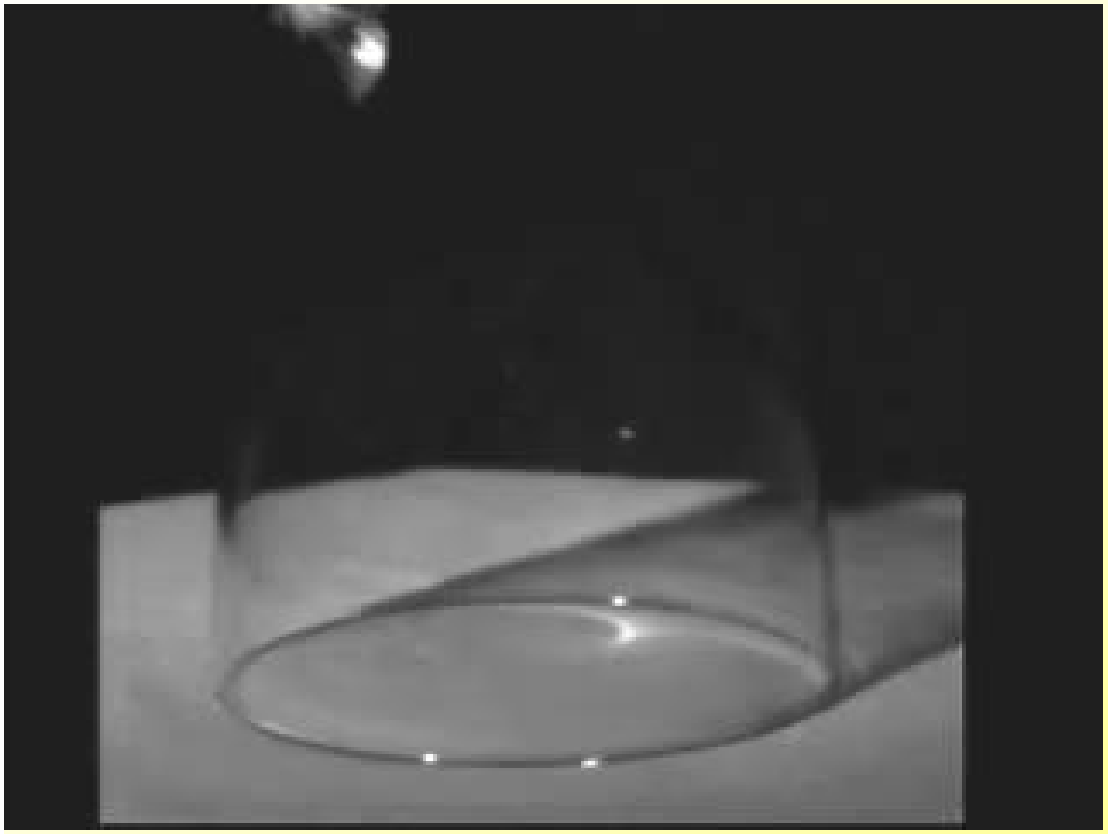
Insect locomotion is used as model for these efforts

Why not use insects directly?

Bee training, insect backpacks have been developed

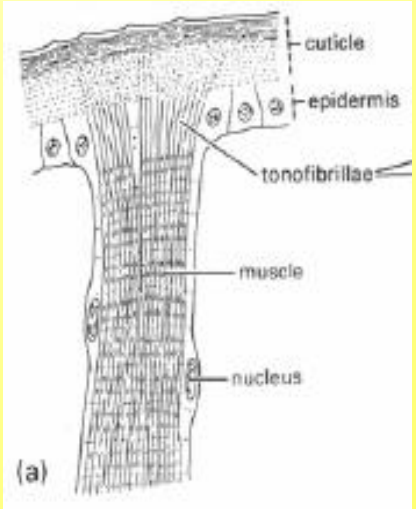
Insight: Control biology using MEMS in a more intimate and economical fashion

Insect advantages



Resilient flight

Built-in-Stealth

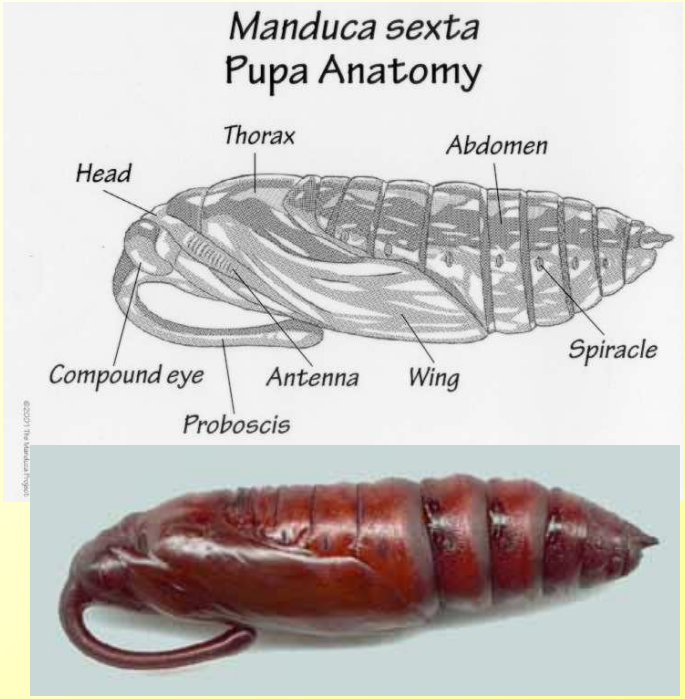


~ 100 Watts/Kg, 10-15% efficient actuators

Background: Insect Metamorphosis

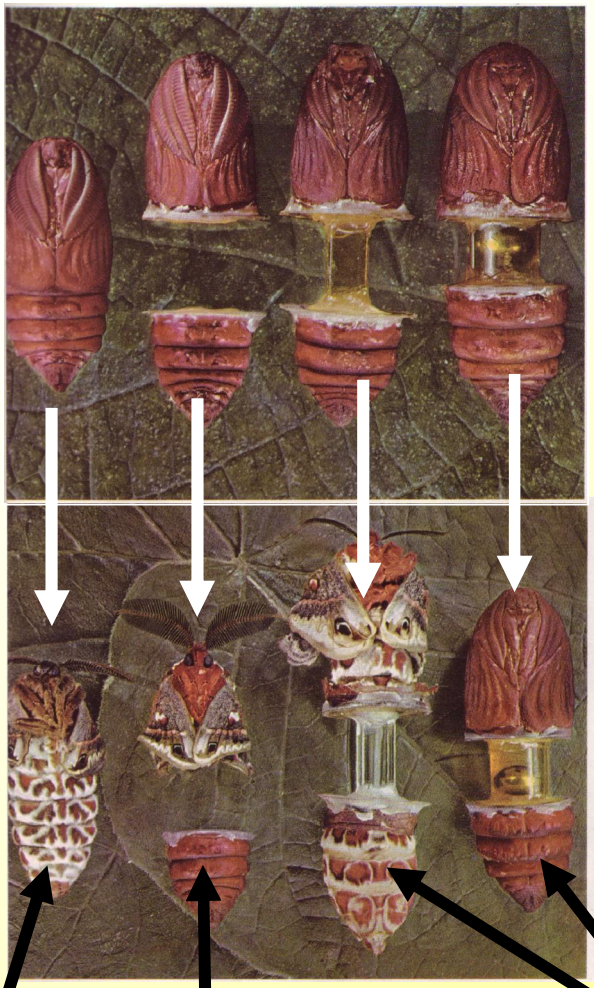
Storage of energy over weeks to use later for flight

1st instar | 2nd instar | 3rd instar | 4th instar | 5th instar



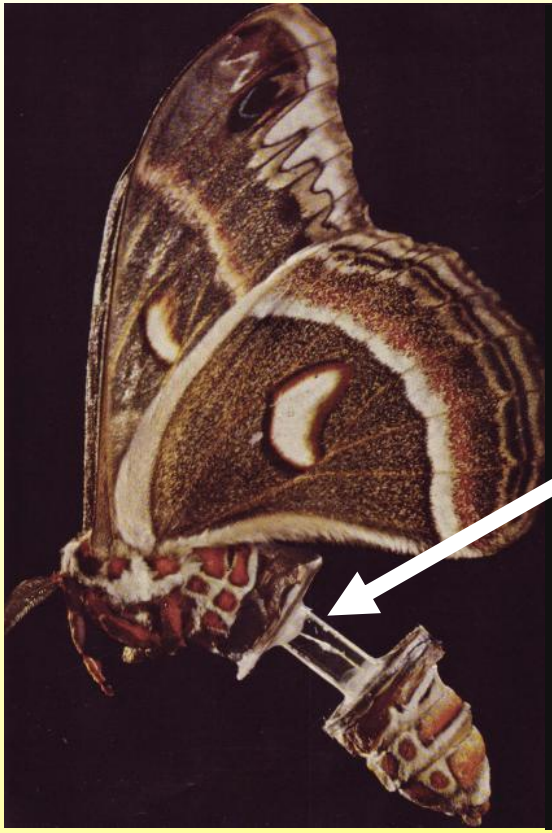
Key Experiments in 1940s

Harvard Entomologist: Carroll Williams



Normal growth

Pupa halved and front develops into moth



DARPA Program : Use object insertion ability into pupas to *reliably* insert microsystems (instead of glass tube) for insect control

Sectioned Pupa with pipe inserted for hormone transport – grows into moth shown above. Insertion of chemical blocking ball bearing results in no growth

Platform with Silicon Chips

Balsa platforms were stitched in the pupae stage

Moth emerges with platform and flies for 2 weeks

- Cornell group has proven successful platform insertion in pupa stage, without effecting flight, or lifetime (To be presented at Solid State Sensors, Actuators, and Misrosystems Workshop, June 2006, Hilton Head Island)
- Ready for locomotion control payloads!

Low Cost Cyborgs

MEMS, BioMEMS, Microfluidics, circuits, MPG

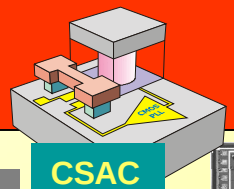
Integrated Circuit - $1-$10

~$1

Micro-UAV – $15

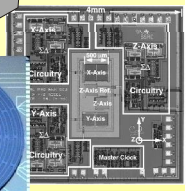
Flight date:

MEMS Platform



CSAC

NGIMG



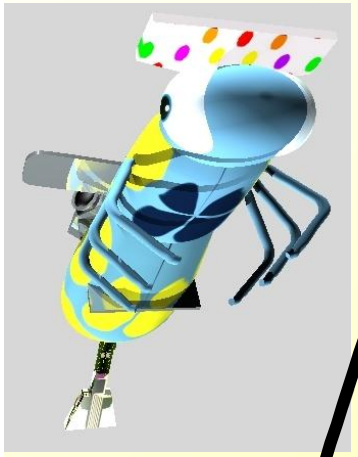
Ultrasonic transducers

Platform for sensors, actuators, and comm

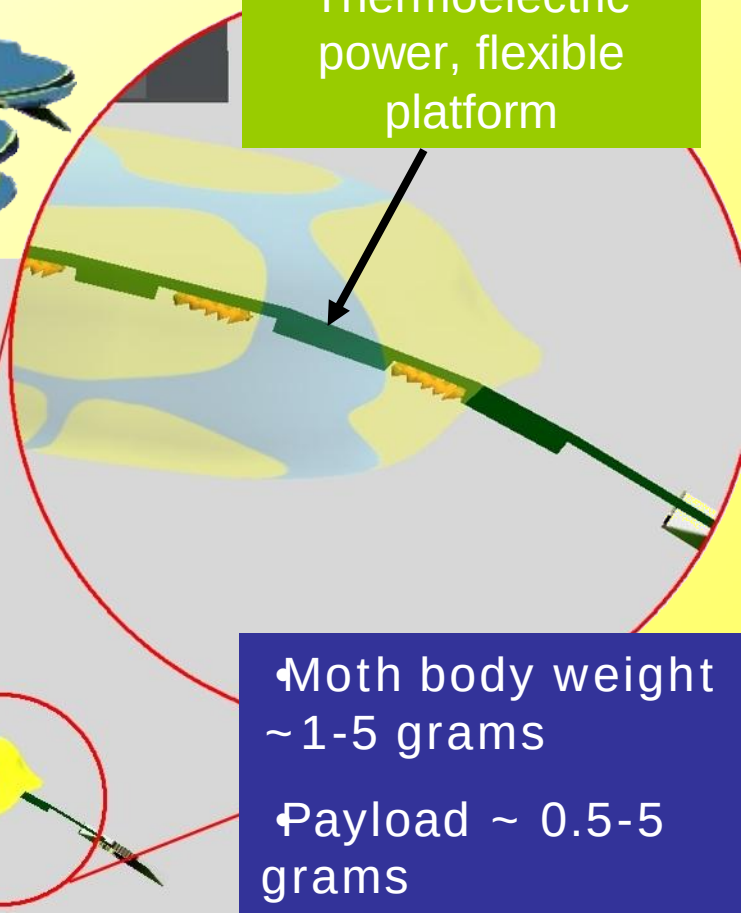
Piezoelectric flaps for power

Pheromone ejectors

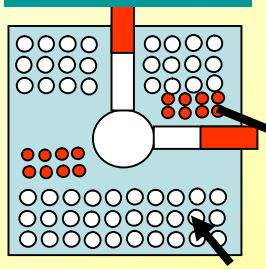
Light sources

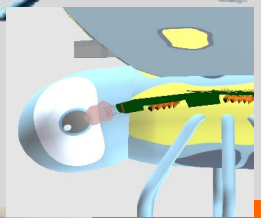


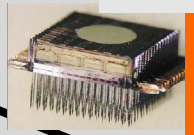
Thermoelectric power, flexible platform



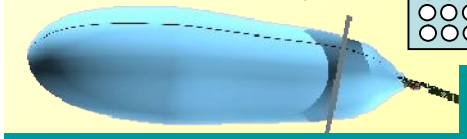
Microfluidic port







Neural/ Muscle probes



Tissue-anchors

Cross and across inserts in pupae

- Moth body weight ~1-5 grams
- Payload ~ 0.5-5 grams

HI-MEMS Propos

New Discipline

MEMS Engineers

Exploit known biology to implement micro sensors and actuators to control insect behavior

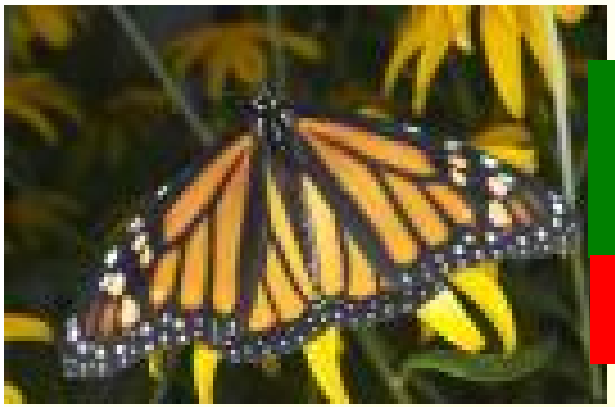
Biologists

Provide biology to MEMS engineers to exploit – maybe discover new biology

Creation of *Insect Cyborg Engineering* Discipline

"Scientists discover the world that exists; engineers create the world that never was." —Theodore Von Karman

Size, speed, distance, height



Monarchs can travel for 3000 miles without feeding for 75 days

Long distance missions

Wingspan 25cm
Larval hostplants = Fabaceae, Legumes
Brazil

Huge payloads

Dragonflies can travel at 45 mph for 2-3 hours

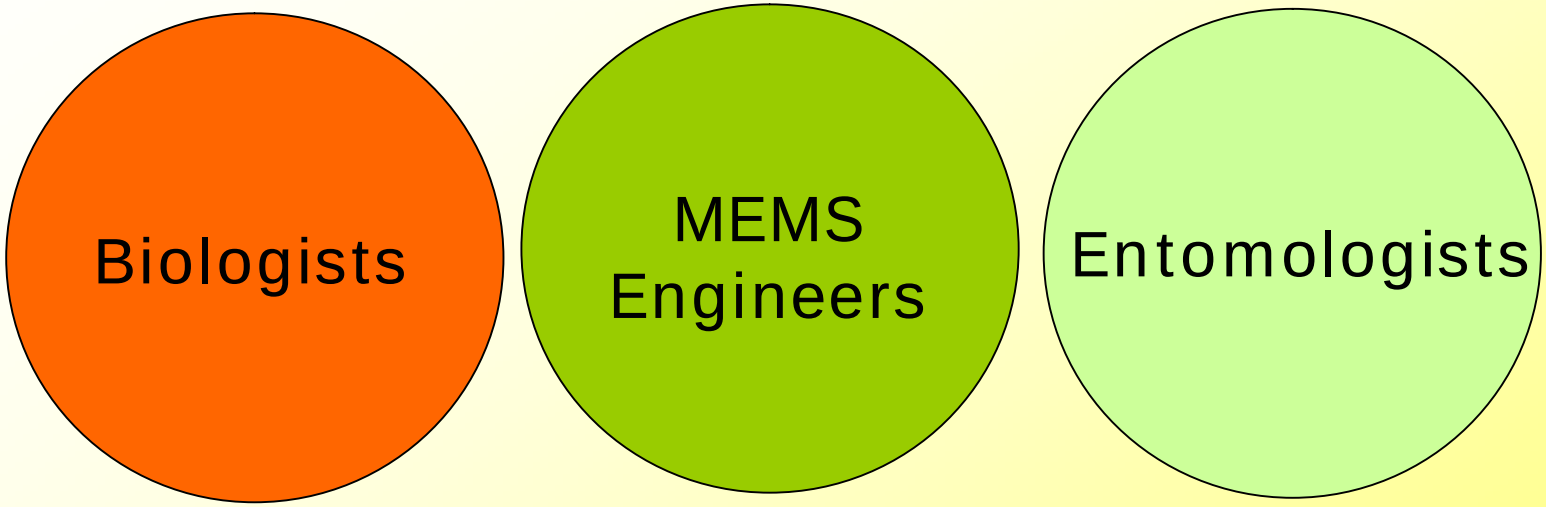
Fast missions

Cocytius duponchel

Wingspan 11-15cm,
Has been collected at 11,000 feet in La Paz, Bolivia

Airborne missions

Team Structure/TASKS

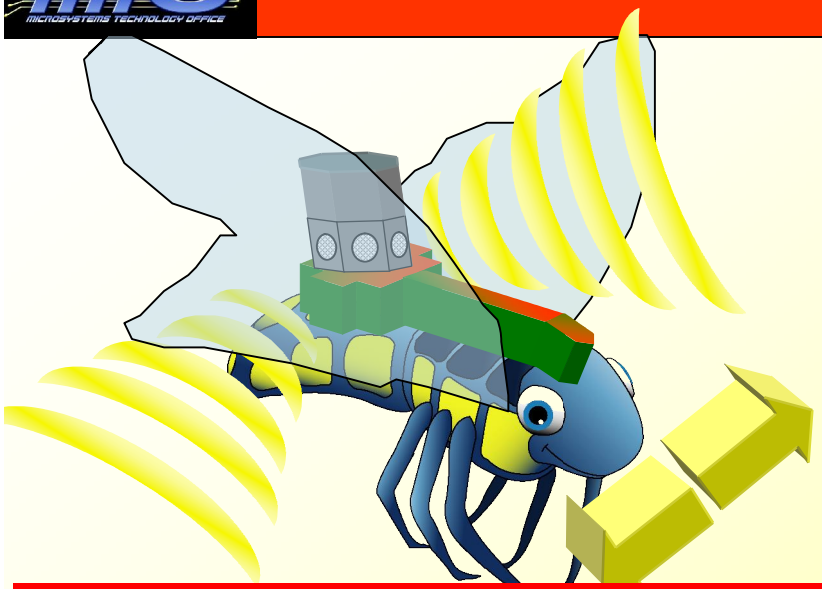


- Demonstrate reliable bio-electromechanical interfaces to insects
- Demonstrate locomotion control using MEMS platforms
- Demonstrate technologies to scavenge power from insects

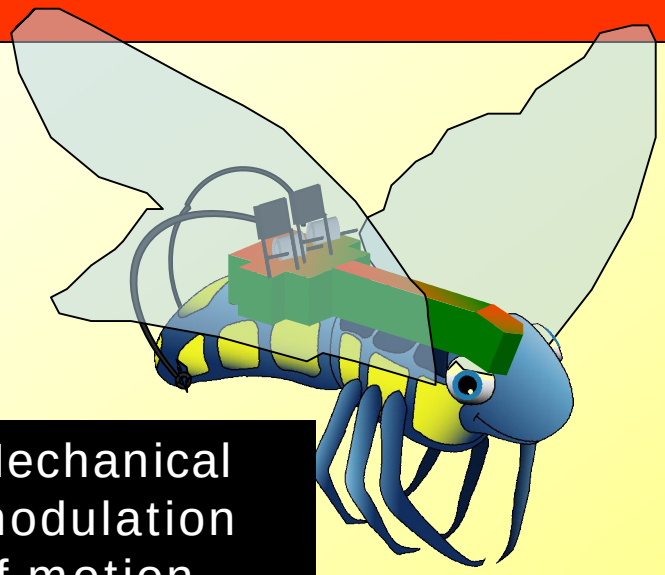
Challenges

- Locomotion control
- Reliable interfaces
- Power generation

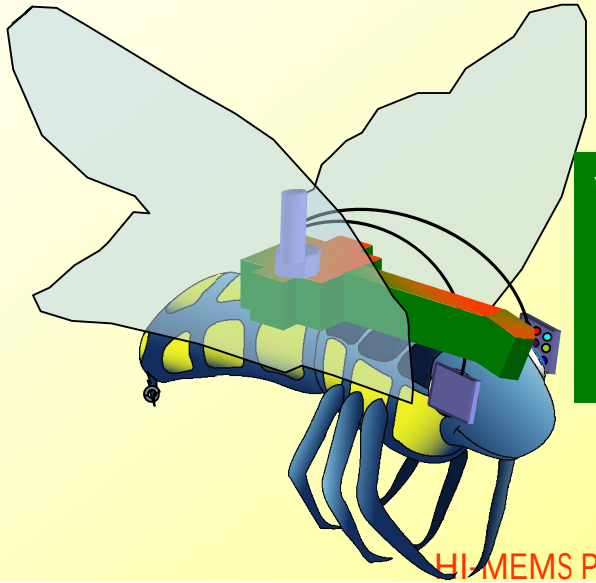
Physical Locomotion control



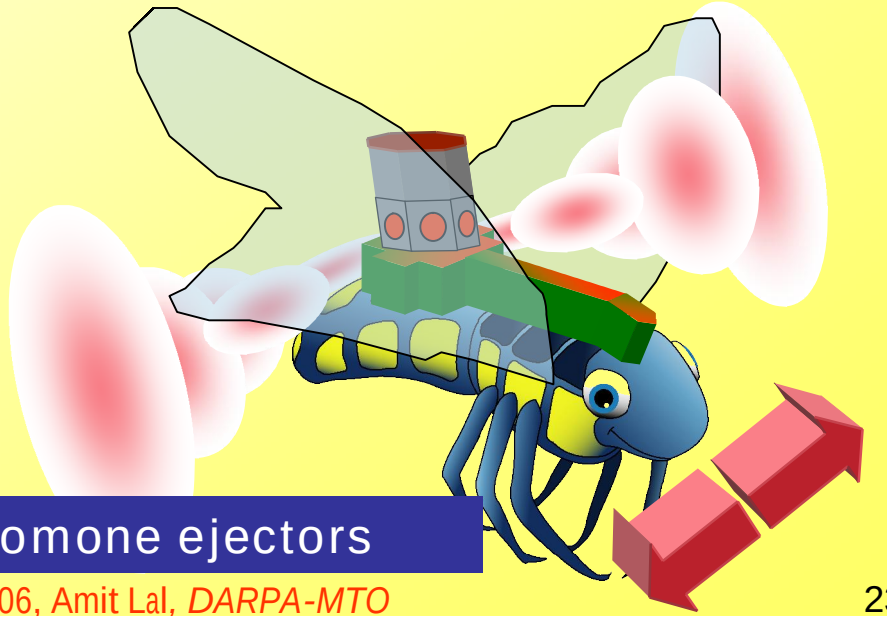
Ultrasonic pulses emulating bats



Mechanical modulation of motion sensors



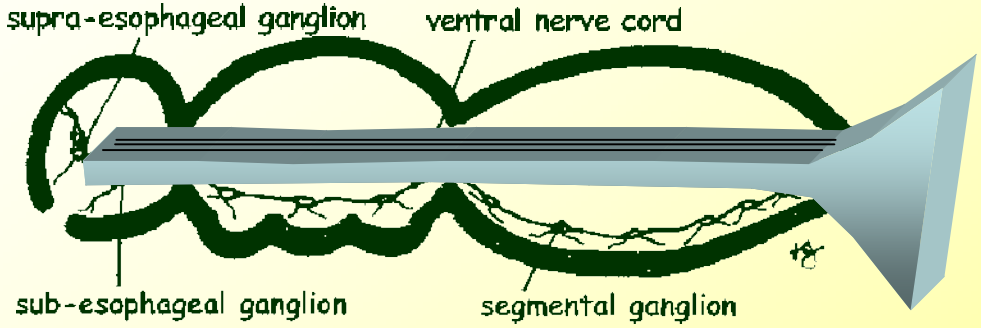
Visual image modulation – 10-20 pixel images



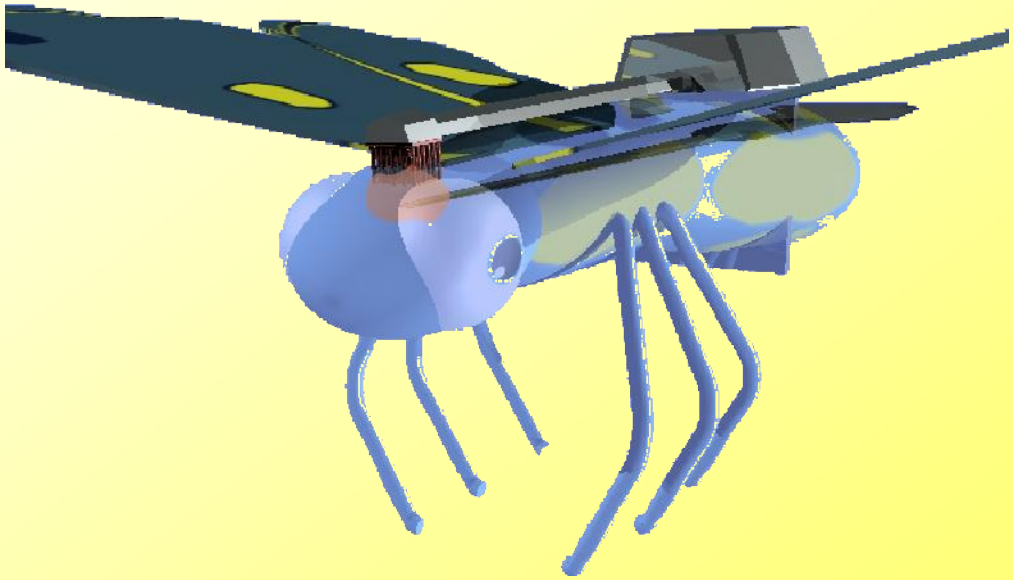
Pheromone ejectors

Neuro-muscular motion control

Direct electrical control of muscles



Neural Probes, Nervous system growth around broken synapses



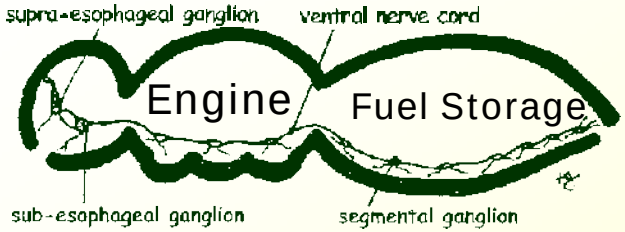
Energy Density of Fuels

Fuel	Energy Density (MJ/Kg)
Carbohydrates	17.2
Proteins	17.2
Fats	38.9
Gasoline	45.8
Jet A	43.3

Muscles are 10-25% efficient

Man-made engines are 20-30% efficient

Power Scavenging Model



Muscle thermal power
~1 W/g
=> ~1 W output for moth

Bio-Battery – can be fed food to get power out

10% muscle to mechanical:
100 mW/g mechanical

Mechanical – electrical
•1 mW w/o affecting flight (1%)
•10 mW power source (10%)

Thermal – electrical
0.25% efficient (ΔT/T = 10/373)*(10%)
~2.7mW

Challenges: Reliable Interfaces

- **Silicon and non-silicon materials**
- **Planar and nonplanar fabrication technologies**
- **Permanent and bioabsorbable materials**
- **Mechanical integrity of links to anatomy**
- **Insertion with minimal damage**

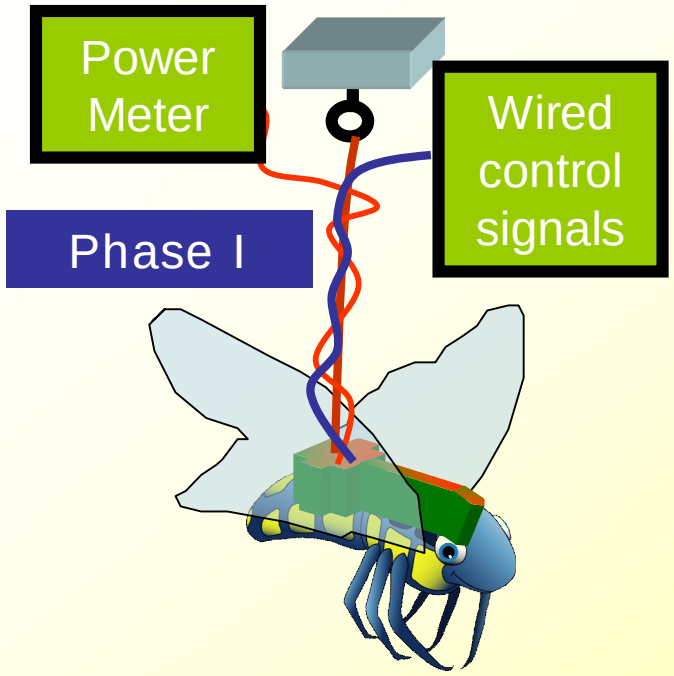
Possible MEMS Components

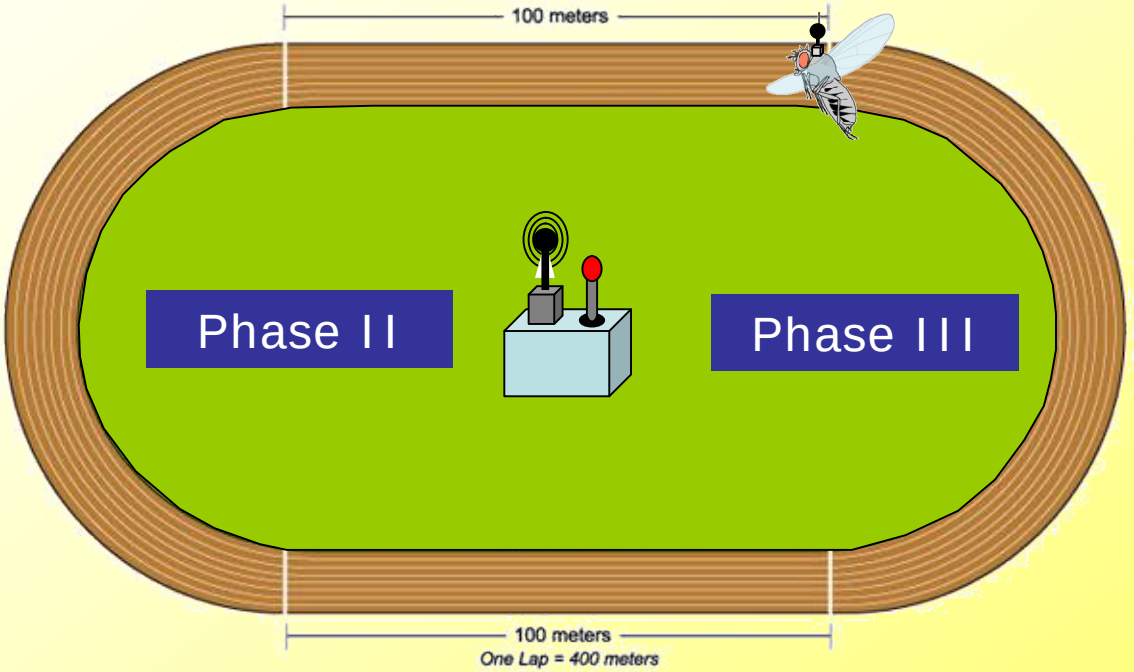
- **Communications** → Low-power RF and sonic microsystems
- **Sensing** → Low power CMOS gas sensors, imagers, acoustic signatures, radiation sensors
- **Navigation** → Low power inertial sensors, low power GPS
- **Power generation** →
  - Vibration power scavenging
  - (Micro) batteries
  - Thermo-electrics

Metrics & Milestones

- Teams determine their own metrics and schedule
- Achieve 5m/100m travel distance and placement accuracy at end of program
- Have the capability of stopping locomotion and transmit sensor information –such as a gas sensor.
- Milestone delivery schedule will be part of selection criteria

Example: Primary Milestones





Specification	State-of-the-Art	Phase 1 (12 months)	Phase 2 (12 months)	Phase 3 (12 months)
Locomotion control accuracy (accuracy/distance)	Roach in lab	Demo	10m/100m	5m/1 mile
Power harvesting	N/A	100 μW	1 mW	10 mW
Reliability of platform interfaces (% of life)	N/A	0.1	0.5	1.0

Secondary Milestones

Specification	State-of-the-Art	Phase 1	Phase 2	Phase 3
Reliable interface to insect brain, muscles (number of neurons/cells being analyzed)	1-5 in the lab	4	10	1000
Control of adult emergence	1 day		1 hour	5 minutes
Camouflage (fraction of machines inside)	Large backpack		0.4	0.9
Insect lifetime enhancement (microfluidic feeding)	N/A		1.5X	3X

MEMS - Exchange

- MEMS Exchange is a DARPA funded service to provide access to microfabrication via a distributed foundry
- http://www.mems-exchange.org/
- The goal of this service is to provide MEMS capability to anyone
- DARPA policy requires that folks submitting to BAA 06-22 use MX for microfabrication, unless they provide waivers