Micro Autonomous Systems and Technology Collaborative Technology Alliance

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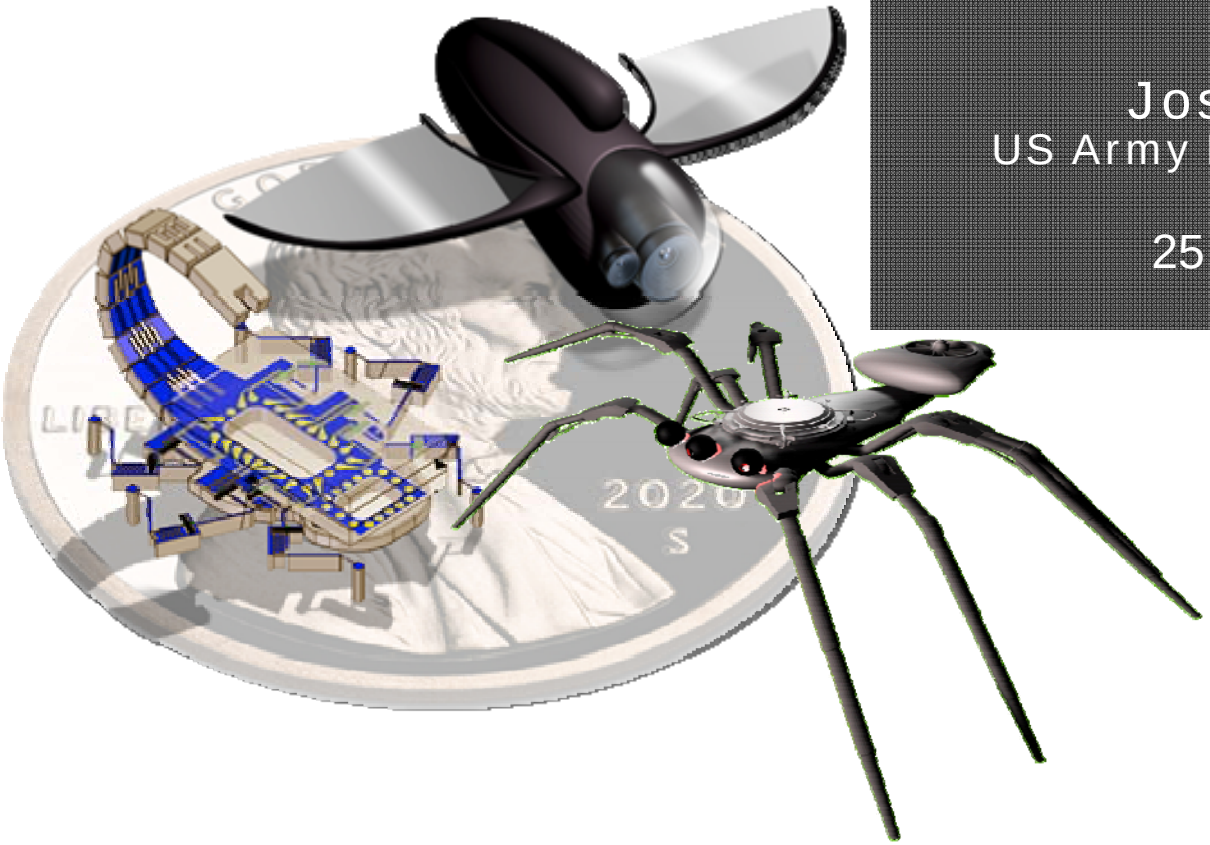
US Army Research Laboratory

25 February 2010

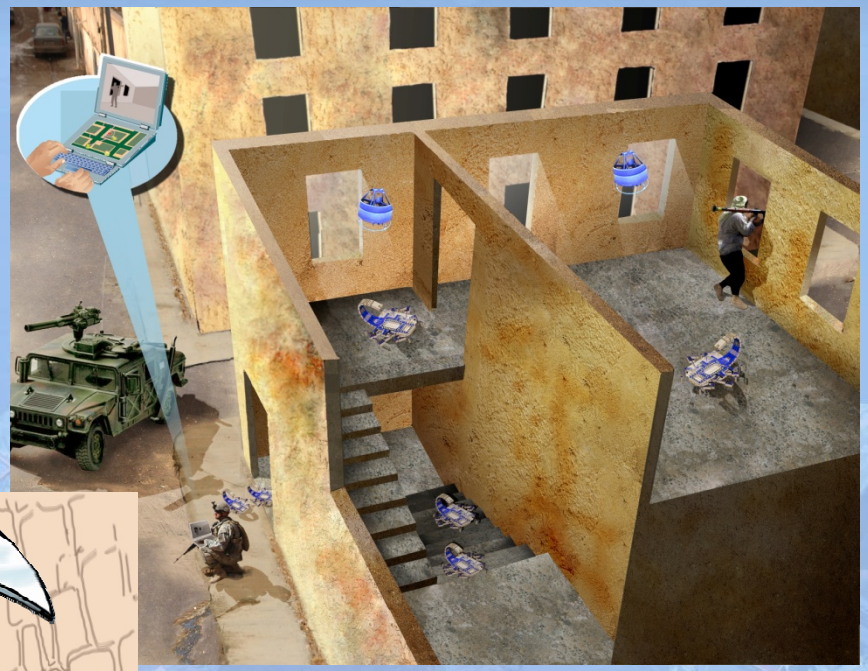


What this Presentation is all about

- Re-emphasize MAST vision, goals, and expectations
  - Metrics for success
- Clarify MAST administration and roles
- Clarify MAST annual process (APP, reviews, etc.)
- Give an indication of what's happening in the next few months

Who I am

- Army Brat: 1958-1980
- Education: PhD EE, Georgia Tech, 1985
- Professional History:
  - 1988-present ARL (presently ST in Electronics & RF)
  - 1984-1988 Assistant EE Professor, UVA
  - Other academic positions
    - 1986, 1990 Visiting Optics Professor, Universität Erlangen (Germany)
    - 1997-2005 Adjunct EE Professor, University of Maryland (College Park)
    - 2001-2004 Research Staff, National Defense University
- Technical Background:
  - primarily optics, imaging, and signal processing
  - Cooperative Agreement Manager for ARL Micro Autonomous Systems and Technology Collaborative Technology Alliance

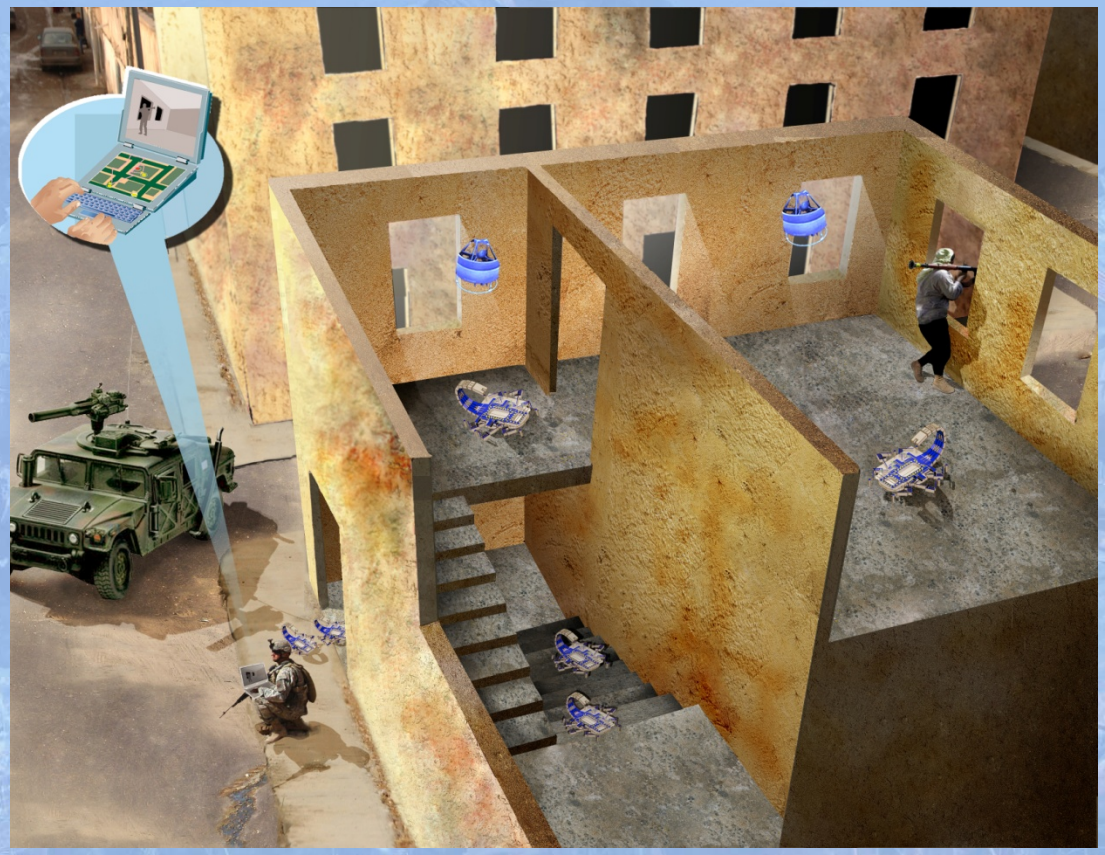


Micro Autonomous Systems and Technology

Collaborative Technology Alliance

Microsystems Vision

To enhance tactical situational awareness
in urban and complex terrain
by enabling the autonomous operation
of a collaborative ensemble of multifunctional, mobile microsystems.



Micro Autonomous Systems and Technology

To enhance tactical situational awareness in urban and complex terrain by enabling the autonomous operation of a collaborative ensemble of multifunctional, mobile microsystems

CTA Vision

- To perform enabling research and transition technology in pursuit of the Microsystems Vision
- To create a critical mass of private sector and Government scientists and engineers focused on solving military technology challenges
- To support and stimulate dual-use applications to benefit commercial use

Shaping the Vision: Operational Scenarios

- **Scenario #1: small unit building search**
  - Autonomous navigation in benign indoor environment with human mission control
- **Scenario #2: small unit cave search or demolished building**
  - Autonomous navigation in complex environment with human mission control
- **Scenario #3: small unit perimeter defense**
  - Autonomous navigation in complex environment with autonomous mission control

Scenario 1

- **Scenario #1: small unit building search**
  - Small number of microsystems map building interior (halls, doorways, rooms) in search of body heat, booby traps(?), and provide pictures
  - Autonomous navigation in benign indoor environment (smooth floors, stairs, quiescent air flow)
  - Human mission control

Scenario 2

- **Scenario #2: small unit cave search or demolished building**
  - Small number of microsystems map unobstructed paths in search of body heat, booby traps(?), and provide pictures
  - Autonomous navigation in complex environment (rough ground surface, unpredictable air flow)
  - Human mission control

Scenario 3

- **Scenario #3: small unit perimeter defense**
  - Small number of microsystems provide perimeter defense (threat detection, threat identification?, threat removal?)
  - Autonomous navigation in complex environment (rough ground surface, gusty wind)
  - Autonomous mission control

Technical Issues

- **Control, perception, & cognition**
  - Autonomous navigation & control
  - Sensing & processing
  - Communication
  - Mobile, distributed sentience
- **Ambulation and aeromechanics**
  - Mechanics in non-benign, complex environments
  - Propulsion & mobility actuation
- **Materials & devices**
  - Heterogeneous integration of devices
  - Mixed signal electronics
- **Platform integration**
  - Microsystem architectures
  - Subsystem interaction
  - Packaging
- **Miniature power and energy**
  - Power integration and management

The overlap and integration between these technical areas drives research.

Micro Autonomous Systems and Technology

- Microsystem Mechanics
- Processing for Autonomous Operation
- Microelectronics
- Platform Integration

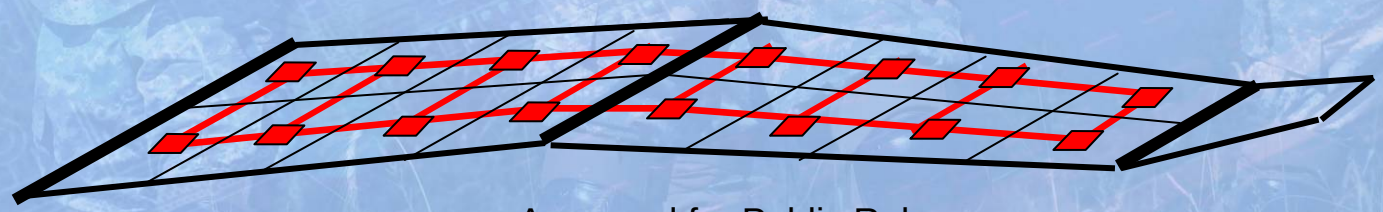
Crosscutting Example

<u>Scenario 2 Challenge:</u>
Autonomous stable flight & navigation in gusty wind

<u>Potential solution: flapping wing with active surface control</u>

- Energy-efficient and gust-tolerant wing design
- Structural energy storage and distributed energy conversion
- Chemical-to-linear force actuators
- Integrated sensing, processing, and actuation for active control
- Embedded devices

  e.g., sensing, processing, actuation, interconnects, energy storage



Integration Issues

- **Integration and experimentation are the keystone for generating empirical data, providing feedback to other Principal Members, and insuring the design process is iterative**
- **Radical design and engineering methodologies are envisioned in which system-level performance is emphasized over the optimization of individual functions**

The Principal Member for Integration
has primary responsibility for
articulating and executing
a vision on cross-Consortium integration.

Collaborative Technology Alliances (CTAs)

Collaboration among
Government-Industry-University researchers
to achieve affordable transition of innovative technologies

- Identify unique Army problems critical to realizing the Future Force Vision that the commercial sector is not solving
- Focus research on technologies to solve these problems
- Plan and execute collaborative basic research jointly with private sector partners in conjunction with Army Research, Development and Engineering Centers (RDECs), other Services, and non-DoD laboratories
- Leverage fast-moving commercial sector technology deployment
- Transition state-of-art technology from the commercial world to the military tech base

MAST CTA Overview

- **Focus: Microsystem Technologies**
  - Autonomous Microsystems critical to future warfighting capabilities
- **Integrated Academic/Industrial/Government Alliance**
  - Basic research
  - Facilitate transition of results for use by government and industry
  - Single award to one consortium
    - Four Principal Members competed independently
    - Government provides Articles of Collaboration
- **5-10 year program starting in May 2007**
- **Builds on success of previous Collaborative Technology Alliances**

Objectives

- To perform enabling research and transition technology in Microsystems
- To enable collaboration across a broad science and technology community
- To create a critical mass of private sector and Government scientists and engineers focused on solving military technology challenges
- To support and stimulate dual-use applications to benefit commercial use

The Alliance

The Alliance

The Consortium

The Government

Lead: Platform Integration	Center: Microsystem Mechanics	Center: Processing for Autonomous Operation	Center: Microelectronics

ARL and Other Government Agencies

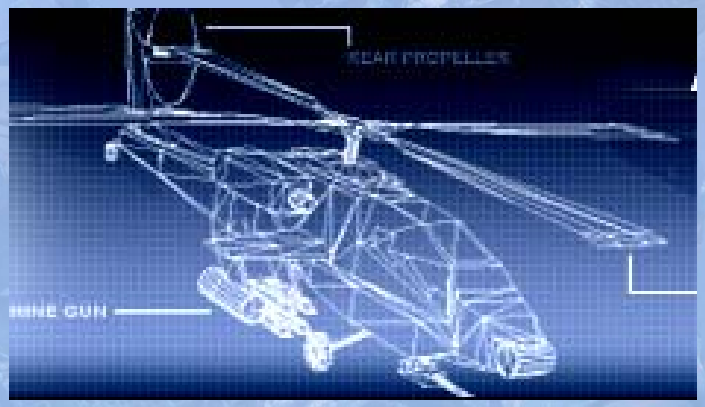
Industrial Principal Member General Member(s)	University Principal Member General Member(s)	University Principal Member General Member(s)	University Principal Member General Member(s)
Government Technical Lead & Collaborators	Government Technical Lead & Collaborators	Government Technical Lead & Collaborators	Government Technical Lead & Collaborators

Consortium Composition

- **Consortium composition**
  - Four Principal Members
    - Principal Member for Integration (limited to U.S. location)
      - Consortium lead
      - Expected (but not required) to be an industrial concern
    - Three Principal Members from academia (no location limitation)
      - Microsystem Mechanics
      - Processing for Autonomous Operation
      - Microelectronics
  - ➢ Independent competition for each Principal Member
  - General Members
    - Each Principal Member is expected to have no more than three
    - HBCU/MI Members
      - Each Research Center must have at least one
    - At least 10% of the funding for each Research Center must be for HBCU/MI Member(s)

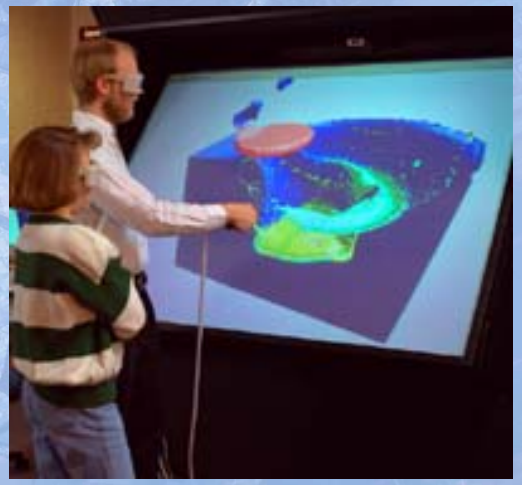
Integrator (Lead)

- Expected, but not required, to be industry
- <u>Responsibilities</u>
  - Leadership
    - Vision
    - Team building, coordination, collaboration
  - Technical administration of CTA
  - Fiscal administration of CTA
  - Vision for & execution of integration tasks
  - Technology transition



Centers

- Academic institution
- Responsibilities
  - Vision for & execution of center tasks
  - Collaboration
    - What does this Center offer to other Principal and Alliance Members?
    - What does this Center require from other Principal and Alliance Members?
  - Technology transition



III. Fundamental Research Component

- **6.1 Basic Research**
- **All results publishable**

IV. Technology Transition Component

- **Contract awarded to the Consortium Lead**
  - Lead is expected to subcontract with other entities within Consortium and with other organizations as appropriate
- **No specific funding budgeted**
  - specific tasks negotiated and issued
- **$80M ceiling over potential 10 year period of performance**

V. Collaboration

- **Features of Collaboration**
  - Collaboration integral to executing research
  - Lectures and Workshops
  - Education Component
  - Staff Rotation among Alliance (Consortium and Government) members
- **Demonstrations**
  - each Principal Member must have demonstration facilities
  - further, funds may be shifted after award to enable a centralized demonstration site

ARL Joppa Facility is primary experimentation site

VI. Management

- **Executive Steering Board**
  - Senior Level Army Personnel
  - addresses issues of US Army policy
- **Research Management Board**
  - representatives from Army, other services, and other Government agency
  - identifies and develops collaborative opportunities, facilitates transition to development programs

VI. Management (cont'd)

- **Collaborative Alliance Manager**
  - senior ARL technical manager
  - responsible for overall technical and fiscal management
- **MAST Program Director**
  - senior Consortium technical representative
  - from Principal Member for Integration
  - responsible for management and guidance of cooperative agreement
- **Center Directors (3)**
  - senior Center technical representative
  - responsible for Center technical leadership, management, and guidance
- **Technical Management Group**
  - chaired by CAM
  - Program and Center Directors
  - corresponding Government technical leads
  - assist in executing responsibilities of CTA

Technical Management Group (TMG)

CAM	Deputy CAM	MAST Program Director
Joseph Mait (301) 394-2462 joseph.mait@us.army.mil	Tom Doligalski (919) 549-4251 thomas.doligalski@us.army.mil	Stephen Scalera (603) 885-2407 stephen.m.scalera@baesystems.com

	Director	ARL Lead
Integration:	Stephen Scalera (603) 885-2407 stephen.m.scalera@baesystems.com	Brett Piekarski (301) 394-1263 brett.piekarski@us.army.mil
Joint Experiments:	Larry Matthies (818) 354-3722 lhm@jpl.nasa.gov	Dan Beekman (301) 394-0920 dan.beekman@us.army.mil
Microsystems Mechanics:	Inderjit Chopra (301) 405-1927 chopra@eng.umd.edu	Mark Bundy (410) 306-0975 mark.bundy@us.army.mil
Microelectronics:	Kamal Sarabandi (734) 764-0500 saraband@umich.edu	William Nothwang (301) 394-1163 william.nothwang@us.army.mil
Processing for Autonomous Operation:	Vijay Kumar (215) 898-3630 kumar@central.cis.upenn.edu	Brian Sadler (301) 394-1239 brian.sadler@us.army.mil

Consortium Management Committee (CMC)

VOTING MEMBERS

Integration (Chair):	Stephen Scalera (603) 885-2407 stephen.m.scalera@baesystems.com
Microsystems Mechanics:	Inderjit Chopra (301) 405-1927 chopra@eng.umd.edu
Micro-electronics:	Karmal Sarabandi (734) 764-0500 saraband@umich.edu
Processing for Autonomous Operation:	Vijay Kumar (215) 898-3630 kumar@central.cis.upenn.edu

GENERAL MEMBERS

California Institute of Technology
Jet Propulsion Laboratory
Georgia Institute of Technology
North Carolina A&T
University of California-Berkeley:
University of New Mexico

EXOFFICIO

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jmait@arl.army.mil

VI. Management (cont'd)

- **Initial Program Plan** ✓
  - IPP based substantially on final proposals from four Principal Members
  - CMC works to develop integrated IPP
  - CAM approves IPP and transmits to Grants Officer
  - IPP accompanied by five-year roadmap
- **Annual Program Plan**
  - Lead and Centers develop plans independently
  - CMC works to develop integrated APP
  - CAM approves APP and transmits to Grants Officer
  - APP may be changed with approval of CAM and Grants Officer

VI. Management (cont'd)

- **Participation in ARL Annual Program Formulation Conference**
- **Evaluation of the Five-year Extension**
  - at the end of fourth year
  - evaluation will consider:
    - cumulative performance metrics
    - consortium's five-year vision
    - funding availability
    - current Army fundamental research needs
- **Collaborative Environment**
  - might be web-based, password protected
  - information repository
  - responsibility of the Lead

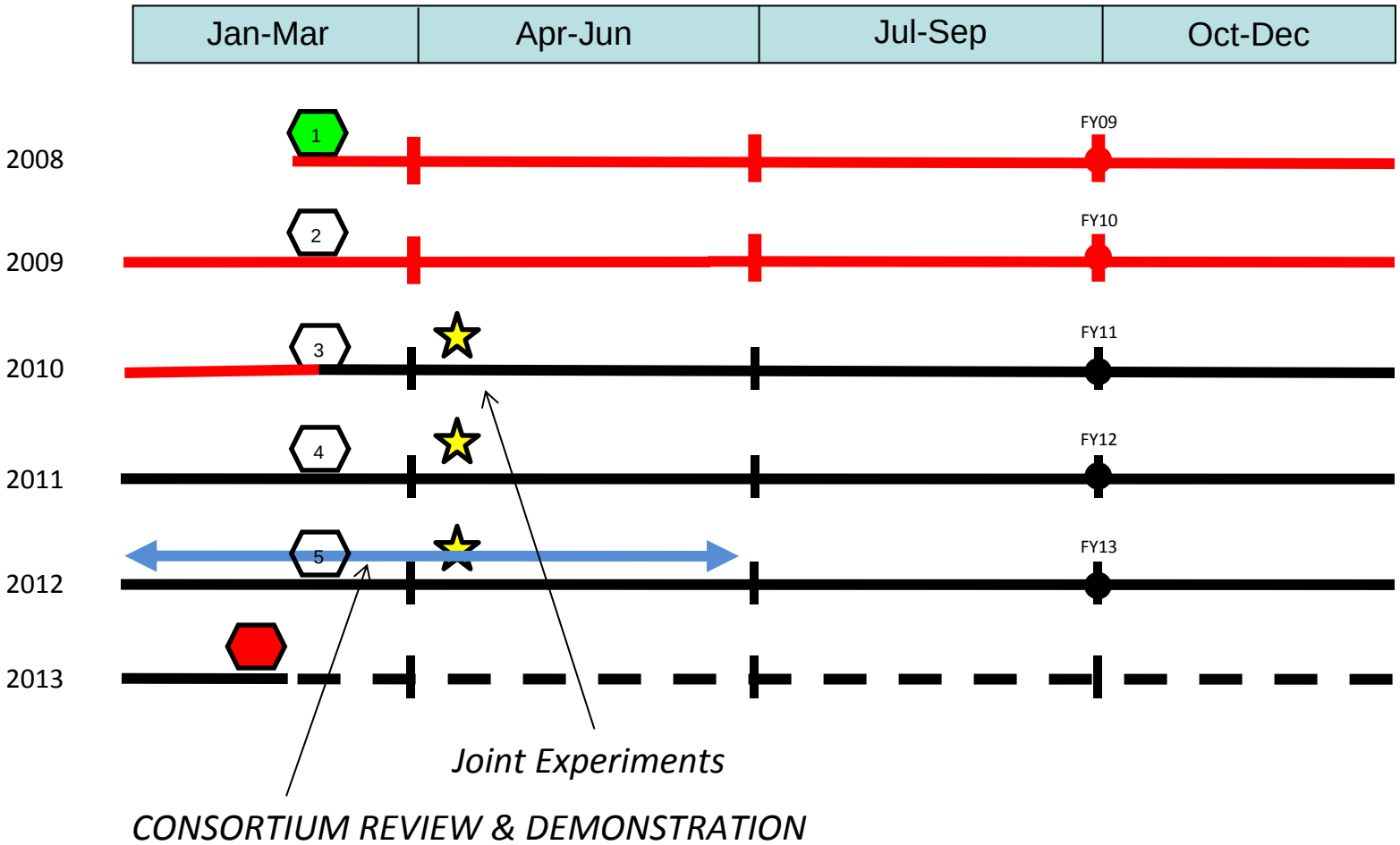
✓ http://alliance.seas.upenn.edu/~mastwiki/wiki/index.php?n=Main.HomePage

Anno Confusion

- Award Date: 28 Feb 2008
- Award Year: 28 Feb YYYY to 27 Feb YYYY+1
- Program Year: 1 Nov YYYY to 31 Oct YYYY+1
- Fiscal Year: 1 Oct YYYY to 30 Sep YYYY+1
- Academic Year: ~Sep YYYY to ~May YYYY+1

MAST Consortium Timeline

5-year program w/possible 5-year extension



Annual Timetable

Mar-Apr	Program Review
May	Alliance Strategic Planning Meeting Ends Review Process, Initiates APP Process
Aug	Industrial Lead submits draft Consortium APP to Alliance members
Mid-Sep	RMB Meeting
Mid-Oct	CMC submits CAM-approved APP to RDECOM Acquisition Center
Nov 1	New Program Year

Homework Assignment

- **Principal Members need to identify and discuss the following issues as they pertain to their area**
  - Scenarios
  - Simulation Environments
  - Demonstrations and Testbed Environments
  - Collaboration
  - Technology transition

Assigned to Principal Members in March 2008 with assignments due at April 28, 2008 PI Meeting at ARL

This is an on-going process.

MAST Vision Statement Remains Unchanged
- Operational Focus on “Last 100 Meters” -

To develop autonomous, multifunctional, collaborative ensembles of agile, mobile microsystems to enhance tactical situational awareness in urban and complex terrain for small unit operations

MAST Scenario Capabilities

- Ground mobility platform
  - (S1) Ability to drive forward (up to 1 m/s) and steer on various terrain
    e.g., smooth vs. rough, solid vs. loose, horizontal vs. vertical
- Air mobility platform
  - Ability to hover in place, translate (up to 2 m/s), maneuver & turn in 1 m radius, change altitude, take off, land, perch,* carry drop-off payloads, all in quiescent (S1) and gusty environments (S2)

*perch involves attachment & detachment on non-horizontal surface

- Sensors
  - (S1) State estimation without GPS or Vicon
  - (S1) Potentially: position and velocity of platforms relative to each other
  - (S1) 360 degree to 4π sr perception for underground and complex 3D environments
  - (S2) Mission sensors (especially to detect and track people and to detect explosives)
  - (S1) Drop-off security sensors with comm
  - (S1) Ability to perceive relevant objects: stairs, closets, intruders, etc.
  - (S1) Ability to navigate and get situational awareness in the dark
  - (S2) Ability to sense air currents for flying in disturbances
  - (S2) Ground contact and body contact sensors for ground vehicles
  - (S2) Ground moisture sensors (??)
  - (S1) All in << 0.5 kg.

MAST Scenario Capabilities (cont'd)

- Communication:
  - (S1) Networked comm between nodes, including option for drop-off repeaters, ability to predict link performance, and ability to plan repeater placement
  - (S1) Ability to transmit imagery
  - (S1) Multiple frequency bands (e.g. 2.4 GHz, 400 MHz) for different propagation environments, throughput requirements, and distance requirements
  - (S2) Transmission in 3-D environments: multi-story buildings, underground tunnels, w/ potential variation in antenna orientation.
- Algorithms:
  - (S1) Obstacle avoidance
  - (S1) Mapping and localization with respect to known map
  - (S1) Coverage planning including maintenance of security as team advances
  - (S2) Ability to fly in gusts
  - (S2) Planning in uncertain, dynamic environments
  - (S1) Coordinated control to concurrently ensure (a) connectivity of team members; (b) achieving eyes on target; and (c) information relay to the human commander
  - (S1) Computational complexity compatible with fast movement with limited computational throughput
  - (S2) Distributed estimation/inference for teams with noisy comm to localize intruders, etc.

MAST Scenario Capabilities (cont'd)

- Computing:
  - (S1) Support all of the above operations with weight << 0.5 kg, power consumption compatible with 10 – 60 minute missions, and throughput compatible with fast motion
  - (S1) Software architecture to support distributed computing, control and fusion
- Endurance:
  - (S1) Propulsion power for O(15 minutes) of mobility; electronics power for O(60 minutes) of observation and communication

Contributing Current Research (cont'd)

- Mobility (cont'd):
  - Ground vehicles:
    - FY10: 4 to 20g crawlers with forward motion and steering on smooth surfaces (M2.1-2.4)
    - FY11: 4 to 20g crawlers with forward motion steering on rough surfaces (M2.1-2.4)
    - FY12: 4 to 20g crawlers with forward motion and steering on loose terrain (M2.1-2.4)
- Sensors
  - iCube for 360° imaging (400-1000 nm)
  - Optic flow sensors, optionally fused with sonar
  - Radar with range and doppler
  - HAIR for airflow and inertial sensing
  - Micro gas chromatograph for explosives, etc.
  - Micro radiation sensor
  - Sensor fusion for non-GPS state estimation with inertial, visual, and other sensors
- Comm:
  - Critical low power components for 400 MHz, 2.4 GHz, and 24 GHz radios.
  - 2.4 GHz repeaters
  - Network comm motes using time-synchronized channel hopping
  - Models and simulation environment for integrating communication, control and perception

Capability Performance Goals

Scenario Capability	Performance Objective	Centers
Ground Platform Mobility: S1 – smooth surface S2- rough surface S3 – horizontal / vertical	Ability to drive forward (@ 1 m/s) and steer 360 deg in 1 platform length	Mechanics Autonomy
Air Platform Mobility: S1- take off/land/perch, quiescent air flow S2 –maneuver / deploy payloads in wind gusts	Ability to hover in place, translate (up to 2 m/s), maneuver/turn in 1 m radius, change altitude 1ft/sec vertical speed Wind: quiescent & gusts (< 10 mph for less than 5 seconds out of 30 sec) Land on flat, horizontal surfaces; drop-off payloads up to 10% of platform payload mass	Mechanics Autonomy Electronics
Micro Sensing S1-Platform state S1-Visual Mapping / Navigation S1 – Detect human targets S2 -Low Light Environment S2- Terrain roughness / traction	Pos/Or: 1-5cm error in 3D position estimate relative to a wall, or other stationary object, 1-5 degree error in 3D orientation estimate relative to a straight object Vel: better than 10% of normal flight speed, and direction within 10 degrees Map: range <10 m in all 3 directions, 1cm resolution, update every 10 secs Visual detection of humans: range < 30m Thermal: detection human body heat/shape: range <15m Terrain roughness: TBD	Mechanics Electronics

What are the metrics for Success?

"Cutting edge research and mind-blowing demonstrations"

John Pellegrino, March 2008

- Necessary but not sufficient
  - Increase fundamental knowledge base in the four CTA areas

    evidence: publications, presentations, and patents
  - Validate relevance of research through technology transition

    evidence: external funding on task order contract

- Necessary and sufficient
  - Increase fundamental knowledge and demonstrate a capability that would not have occurred without the insights and perspectives of several Alliance members

    evidence:
    - *joint* publications, presentations, and patents
    - external funding on task order contract that supports *more than one* consortium member

Review Criteria

- Overview
- Technical Relevance
- Relevance to MAST
- Technical Accomplishments
- Collaboration
- Leveraged Efforts
- Future Plans
- Metrics

Collaboration and Joint Experimentation

- Describe any efforts that have been made to coordinate efforts within and between centers
  What is needed from other centers to improve further upon technology development?
- Does your effort feed into joint experiments in the near future? If not, will it at some point?
  Note: This is not a requirement. We do not expect all tasks to feed into joint experiments, especially ones that require more research to mature

From MAST 2010 Review Template

•Not all tasks must be collaborative but where collaboration is possible ARL expects to see it

FY10 Joint Experiments

J1.1 Stabilization of aircraft in gusts using Vicon
J1.2 Reactive obstacle avoidance for ground vehicles using optical flow and sonar
J1.3 Image transmission through buildings using drop-off mote mesh network

J2.1 Vision-guided landing on mock-up rooftop
J2.2 Vision-guided flight through mock-up door/window
J2.3 Embedded antennas for air and ground vehicles, including embedded solar cells
J2.4 Integrated point-sampling sensors (µGC, µGeiger, HAIR airflow)
J2.5 Simulation of radar sensor and radar-based obstacle avoidance

J3.1 Coordinated ground robot SLAM with basic door recognition
J3.2 Robot ensemble communication with drop-off repeaters, with precomputed locations

Joint Experiments

- Are experiments and not demos!
- are necessary for collaborative CTA success but not sufficient
- continue throughout the year
- build up year-over-year
- combine research breakthroughs from the previous year
- culminate in the Final Consortium Demonstration

Near-Term Activities

- March 8: State of the CTA presentation
- March: CTA reviews
- March – May: Submission window for White Papers from non-CTA investigators
- April – May: Joint Experiments
- May 27: Strategic Planning Meeting
- June 19: Robot Fair@Berkeley

Long-Term Activity Goals

- Increased Webinars
  - Twice monthly (6 per Center per year)
  - Examples
    - State of the CTA (modified)
    - Student and post-doc projects
- Workshops
- Working groups

Questions?