BIOMORPHIC EXPLORERS

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DARPA WORKSHOP on Biologically Inspired Approaches for MAV's
April 21-22, 1999, Alexandria, VA
BIOMORPHIC EXPLORERS

- SMALL, DEDICATED, LOW-COST EXPLORERS THAT CAPTURE SOME OF THE KEY FEATURES OF BIOLOGICAL EXPLORERS

- CONDUCTED WORKSHOP, AUG 19-20, 1998
  - SPONSORED BY NASA/JPL
  - VERY SUCCESSFUL; OVER 150 PARTICIPANTS
BIOMORPHIC EXPLORERS

OPENING REMARKS
FIRST NASA/JPL WORKSHOP ON
BIOMORPHIC EXPLORERS FOR FUTURE MISSIONS

Dr. Peter B. Ulrich

"The fiscal and physics constraints we face will, in Darwinian fashion, lead us to do what nature does so well...economize and minimize. Emerging from that vision, the Biomorphic Explorer will be an economic and minimalist marvel that captures the best that nature has to offer"
Biomorphic Explorers: Classification
(Based on Mobility and Ambient Environment)

Biomorphic Explorers

Aerial

Surface/Subsurface

Biomorphic Surface Systems

Biomorphic Subsurface Systems

Seed Wing
Honey Bee
Ant
Centipede
Snake
Soaring Bird
Humming Bird
Earthworm
Jelly Fish
Germinating Seed

Examples of biological systems that serve as inspiration for designing the biomorphic explorers in each class
Biomorphic Explorers: Classification
(Based on Mobility and Ambient Environment)

**Biomorphic Explorers**

- **Aerial**
  - Seed Wing Flyer (60 g)
  - Ornithopter
  - Glider (75 g)
  - Powered Flyer

- **Surface/Subsurface**
  - **Biomorphic Surface Systems**
    - Hexapod (1-2 kg)
    - Reconfigurable Legs/Feet
    - Artificial Earthworm
  - **Biomorphic Subsurface Systems**
    - Artificial Jelly Fish
    - Worm Robot (85 g)

*Candidate biomorphic explorers on the drawing board, with mass of design under study in 1998 in parentheses*
KEY FEATURES

• VERSATILE MOBILITY: aerial, surface, subsurface, and in fluids
• ADAPTIVE, DISTRIBUTED OPERATION
• BIOMORPHIC COMMUNICATIONS
• BIOMORPHIC SENSOR FUSION
• BIOMORPHIC COOPERATIVE BEHAVIOR
Biomorphic Flight Systems: Vision

- Extended reach over all kinds of terrain
- Unique perspective for imaging and Spectral Signature
- Many flyers work in cooperation with larger aircraft, and balloons to enable new missions to reach currently inaccessible locations
Biomorphic flight systems offer rapid mobility and extended reach. For comparison the above illustrates for the same total mass of the system, the respective payload fractions in each case.
BIOMORPHIC EXPLORERS

- PAYOFF

- BIOMORPHIC EXPLORERS, IN COOPERATION WITH CURRENT EXPLORATION PLATFORMS CAN ENABLE
  - EXPLORATION OF CURRENTLY INACCESSIBLE AND/OR HAZARDOUS LOCATIONS
  - MUCH BROADER COVERAGE OF EXPLORATION SITES
  - EXPLORATION AT LOWER COST
Biomorphic Explorer: Conceptual Design

Biomorphic Cooperative Behavior
Biomorphic Control Algorithms

μSensors

Reconfigurability

Advanced Mobility

μNavigation

μCommunication

Temperature Control

μStructure

μComputing

μPower

GLIDER SELECTED

SELECTION CRITERIA
- Low Mass/Volume
- High Payload Fraction
- Large Range of Mobility
- Active Control
- Implementation Readiness

GLIDER BASELINE DESIGN CHARACTERISTICS
- Mass: 75 g
- Payload Fraction: 60%
- Glide Ratio, L/D ~ 5.8
- Large Range of Aerial Mobility: ~50 km to 100 km
- Leverage from MAV Technology
- Volume: 300 cm³
- Active Flight Control
- Solar Navigation
- Soaring Flight in Rising Currents
- Cooperative Mission: 32 Gliders
- Coverage Area: ~100 km x 100 km

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Biomorphic Gliders

- Small, simple, low-cost system ideal for distributed measurements, reconnaissance and wide-area dispersion of sensors and small experiments.
- Payload mass fraction 50% or higher.
  - small mass (100 g - 500 g)
  - low radar cross section
  - larger numbers for given payload due to low mass
  - amenable to cooperative behaviors
  - missions use potential energy: deploy from existing craft at high altitude
  - Captures features of soaring birds, utilizing rising currents in the environment
  - Adaptive Behavior
  - Self Repair features
BIOMORPHIC EXPLORERS

Biomorphic Gliders

- Small, simple, low-cost system ideal for reconnaissance and wide-area dispersion of sensors and small experiments.
- Payload mass fraction 50% or higher.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Mass (M)</td>
<td>57 75 250 500 g</td>
</tr>
<tr>
<td>Payload (P)</td>
<td>32 45 150 300 g</td>
</tr>
<tr>
<td>P/M fraction</td>
<td>56 60 60 60 %</td>
</tr>
<tr>
<td>Wing Span</td>
<td>0.19 0.25 0.50 0.76 m</td>
</tr>
<tr>
<td>Wing Area</td>
<td>0.014 0.021 0.071 0.143 m²</td>
</tr>
<tr>
<td>Volume</td>
<td>168 300 1700 5200 cm³</td>
</tr>
<tr>
<td>Flight Speed</td>
<td>90 90 90 90 m/s</td>
</tr>
<tr>
<td>Range</td>
<td>50 55 72 83 km</td>
</tr>
<tr>
<td>Duration</td>
<td>590 650 800 1300 s</td>
</tr>
<tr>
<td>Glide Ratio</td>
<td>5.3 5.8 7.5 8.6</td>
</tr>
<tr>
<td>Starting Alt.</td>
<td>10 10 10 10 km</td>
</tr>
</tbody>
</table>

- Performance calculations based on conditions at 5 km altitude on Mars for a glider that has an analog 2gm camera
- Volume based on projected area x mean thickness x 1.2
Biomorphic Glider Deployment Concept: Larger Glider Deploy/Local Relay

- Probe enters atmosphere
- Parachute deployed

Heat shield released and antenna deployed (14 km).

Larger Aircraft (Large Glider) released (13 km)

Large Glider flies preset flight plan deploying the biomorphic gliders

LARGER GLIDER/AIRCRAFT

Local relay collects and transmits data to orbiter

Gliders transmit data to local relay.

COM PORT 1

COM PORT 2

JAVELIN

LANDER ROVER

Surface measurements

Biomorphic Gliders perform in-flight measurements (12-km to surface)

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Biomorphic Glider Deployment Concept: Probe Deploy/Lander Relay

Gliders fly preset flight plans based on Sun position.

LANDER ROVER

COM PORT 1

Surface measurements

Relay to Earth

Lander (local relay) collects and transmits data to earth relay.

Gliders transmit data to local relay.

JAVALIN

COM PORT 2

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Biomorphic Glider Deployment/Telecommunication Concept

Probe enters atmosphere
Parachute deployed

Heat shield and gliders released (12-14 km).

In flight measurements (12 km to surface)

Gliders transmit data to local relay using self-organized, self-routing network, which changes dynamically during the flight and after landing, to communicate optimally the information to the local relay.

LANDER ROVER
COM PORT 1

JAVELIN
COM PORT 2

Surface measurements
BIOMORPHIC EXPLORERS

SUMMARY & ROADMAP
Enabling better spatial coverage and access to hard-to-reach and hazardous areas at low recurring cost

BIOMORPHIC COOPERATIVE BEHAVIOR
BIOMORPHIC CONTROL ALGORITHMS

µSENSORS

µCOMMUNICATION
TEMPERATURE CONTROL

µSTRUCTURE

ADVANCED MOBILITY

µPOWER

µNAVIGATION

µCOMPUTING

1997  2002  2007  2012?

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BIOMORPHIC EXPLORERS

COORDINATED/COOPERATIVE EXPLORATION SCENARIO

ATMOSPHERIC INFO GATHERING:
- DISTRIBUTED MULTIPLE SITE MEASUREMENTS
- CLOSE-UP IMAGING, EXOBIOLOGY SITE SELECTION
- DEPLOY PAYLOAD: INSTRUMENTS/CRAWLERS
- SAMPLE RETURN RECONNAISSANCE

LANDER/ROVER

Biomorphics Crawlers

COM PORT 1

INFO DOWNLINK TO PENETRATOR

INACCESSIBLE
AREA

COOPERATIVE ORGANIZATION OF LANDER, ROVER, AND A VARIETY OF INEXPENSIVE BIOMORPHIC EXPLORERS WOULD ALLOW COMPREHENSIVE EXPLORATION AT LOWER COST WITH BROADER COVERAGE.
Applications

- Distributed Aerial Measurements
  - Ephemeroid Phenomena
  - Extended Duration using Soaring

- Delivery and lateral distribution of Agents (sensors, surface/subsurface crawlers, clean-up agents)

- Close-up Imaging, Site Selection
  - Meteorological Events: storm watch
  - Reconnaissance
  - Biological Chemical Warfare
  - Search and Rescue etc
  - Surveillance
  - Jamming
ACKNOWLEDGMENTS

The research described in this document was carried out by the Jet Propulsion Laboratory (JPL), California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA).

The following people contributed useful inputs and/or suggestions:

Carlos Miralles, AeroVironment
Ali Hazimiri, Caltech
Bruce Kwan, JPL
Don Kurtz, JPL

Paul MacCready, AeroVironment
Dave Rutledge, Caltech
Anil Thakoor, JPL