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
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  Earthworm  Germinating Seed

Soaring Bird  Humming Bird  Snake  Jelly Fish

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

Surface/Subsurface

Biomorphic Surface Systems

Biomorphic Subsurface Systems

Seed Wing Flyer (60 g)
Ornithopter
Glider (75 g)
Powered Flyer

Hexapod (1-2 kg)
Reconfigurable Legs/Feet

Artificial Earthworm
Worm Robot (85 g)

Artificial Jelly Fish

Candidate biomorphic explorers on the drawing board, with mass of design under study in 1998 in parentheses
BIOMORPHIC EXPLORERS

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 EXPLORERS

BIOMORPHIC FLIGHT SYSTEMS

a. Seed Wing Pod

TOTAL MASS: 57 g
PAYLOAD MASS: 48 g

b. Seed Wing Pod Flyer

TOTAL MASS: 57 g
PAYLOAD MASS: 32 g

c. Biomorphic Glider

TOTAL MASS: 57 g
PAYLOAD MASS: 6 g

d. Biomorphic Flyer

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.

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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 EXPLORERS

BIOMORPHIC COOPERATIVE BEHAVIOR
BIOMORPHIC CONTROL
ALGORITHMS

μSENSORS
RECONFIGURABILITY
ADVANCED MOBILITY
μNAVIGATION

μCOMMUNICATION
TEMPERATURE CONTROL
μSTRUCTURE
μCOMPUTING
μPOWER

GLIDER SELECTED

<table>
<thead>
<tr>
<th>SELECTION CRITERIA</th>
<th>GLIDER BASELINE DESIGN CHARACTERISTICS</th>
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</thead>
<tbody>
<tr>
<td>• LOW MASS/VOLUME</td>
<td>• MASS: 75 g</td>
</tr>
<tr>
<td>• HIGH PAYLOAD FRACTION</td>
<td>• PAYLOAD FRACTION: 60 %</td>
</tr>
<tr>
<td>• LARGE RANGE OF MOBILITY</td>
<td>• GLIDE RATIO, L/D ~ 5.8</td>
</tr>
<tr>
<td>• ACTIVE CONTROL</td>
<td>• LARGE RANGE OF AERIAL MOBILITY: ~ 50 km to 100 km</td>
</tr>
<tr>
<td>• IMPLEMENTATION READINESS</td>
<td>• LEVERAGE FROM MAV TECHNOLOGY</td>
</tr>
<tr>
<td></td>
<td>• VOLUME: 300 cm³</td>
</tr>
<tr>
<td></td>
<td>• ACTIVE FLIGHT CONTROL</td>
</tr>
<tr>
<td></td>
<td>• SOLAR NAVIGATION</td>
</tr>
<tr>
<td></td>
<td>• SOARING FLIGHT IN RISING CURRENTS</td>
</tr>
<tr>
<td></td>
<td>• COOPERATIVE MISSION: 32 GLIDERS</td>
</tr>
<tr>
<td></td>
<td>• COVERAGE AREA: ~100 km x 100 km</td>
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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 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>
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<tr>
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<th>Baseline</th>
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<tr>
<td>Total Mass (M)</td>
<td>57</td>
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<tr>
<td>Payload (P)</td>
<td>32</td>
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<tr>
<td>P/M fraction</td>
<td>56</td>
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<tr>
<td>Wing Span</td>
<td>0.19</td>
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<tr>
<td>Wing Area</td>
<td>0.014</td>
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<tr>
<td>Volume</td>
<td>168</td>
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<tr>
<td>Flight Speed</td>
<td>90</td>
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<tr>
<td>Range</td>
<td>50</td>
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<tr>
<td>Duration</td>
<td>590</td>
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<tr>
<td>Glide Ratio</td>
<td>5.3</td>
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<tr>
<td>Starting Alt.</td>
<td>10</td>
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</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

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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

COM PORT 1

LANDER ROVER
Surface measurements

Biomorphic Gliders perform in-flight measurements (412 km to surface)

Local relay collects and transmits data to orbiter
Gliders transmit data to local relay.
COM PORT 2
JAVELIN

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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

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

Gliders transmit data to local relay.

JAVELIN

COM PORT 2

Relay to Earth
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

JAVELIN

COM PORT 1

COM PORT 2

Surface measurements

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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

BIOMORPHIC FLYERS

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

LANDER/ROVER

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

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Applications

- Distributed Aerial Measurements
  - Ephemerai 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

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