BIOMORPHIC EXPLORERS

Sarita Thakoor

biological systems
cooperative behaviors
sensor fusion
distributed operation
versatile mobility

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109-8099

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

sarita.thakoor@jpl.nasa.gov

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

sarita.thakoor@jpl.nasa.gov

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"

sarita.thakoor@jpl.nasa.gov

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

Jelly Fish

Earthworm

Germinating Seed

Soaring Bird

Humming Bird

Snake

Examples of biological systems that serve as inspiration for designing the biomorphic explorers in each class

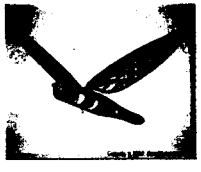
sarita.thakoor@jpl.nasa.gov

Biomorphic Explorers: Classification (Based on Mobility and Ambient Environment)

Biomorphic Explorers

Aerial

Seed Wing Flyer (60 g)



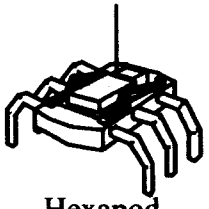
Ornithopter

Glider (75 g)

Powered Flyer

Surface/Subsurface

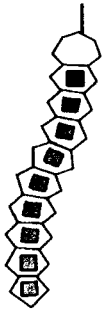
Biomorphic Surface Systems



Hexapod (1-2 kg)

Reconfigurable Legs/Feet

Biomorphic Subsurface Systems



Artificial Jelly Fish

Artificial Earthworm

Worm Robot (85 g)

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

sarita.thakoor@jpl.nasa.gov

BIOMORPHIC EXPLORERS

- **KEY FEATURES**
  - **VERSATILE MOBILITY: aerial, surface, subsurface, and in fluids**
  - **ADAPTIVE, DISTRIBUTED OPERATION**
  - **BIOMORPHIC COMMUNICATIONS**
  - **BIOMORPHIC SENSOR FUSION**
  - **BIOMORPHIC COOPERATIVE BEHAVIOR**

sarita.thakoor@jpl.nasa.gov

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

sarita.thakoor@jpl.nasa.gov

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

sarita.thakoor@jpl.nasa.gov

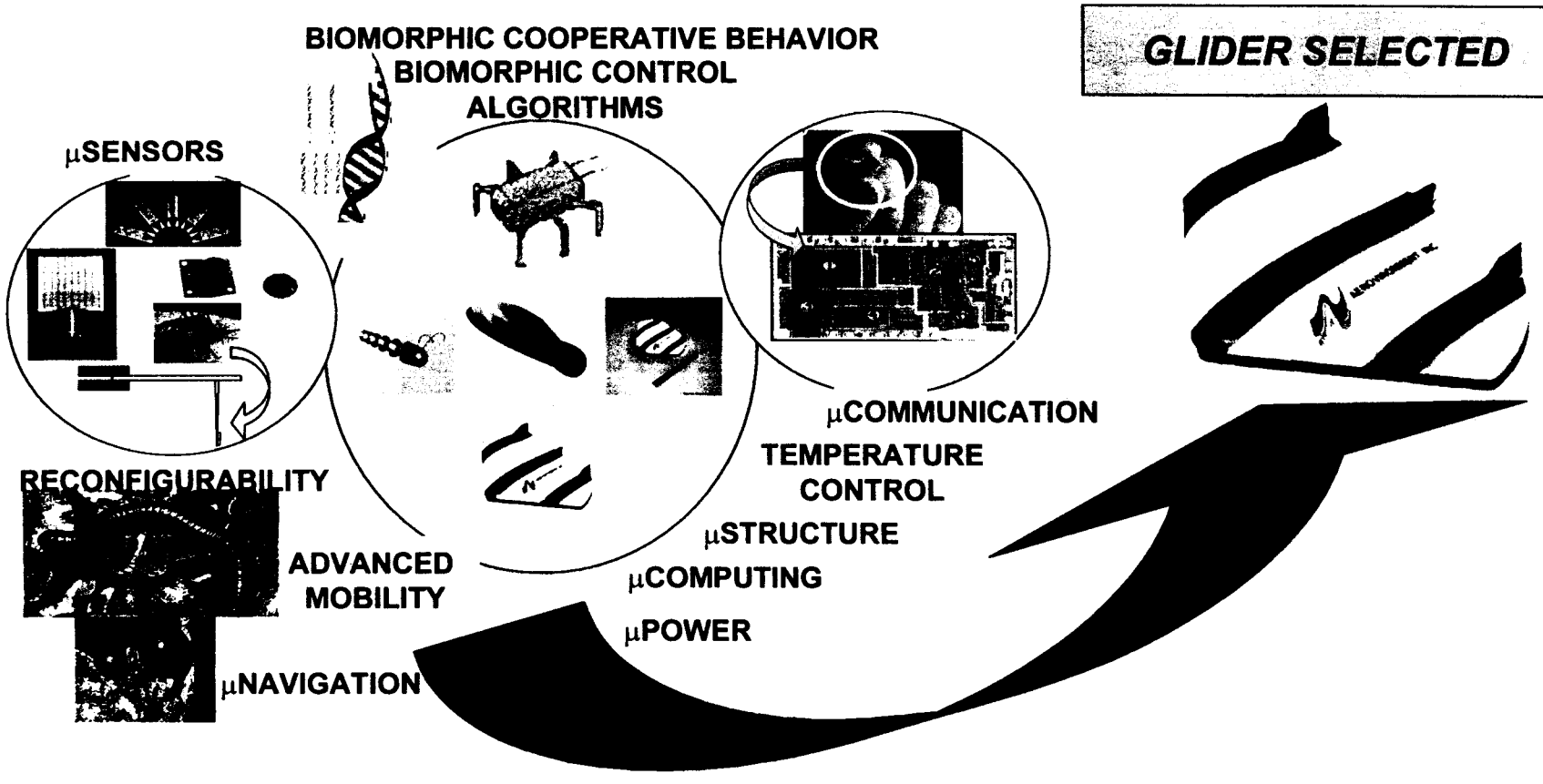
BIOMORPHIC EXPLORERS

- **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**

sarita.thakoor@jpl.nasa.gov

Biomorphic Explorer: Conceptual Design



SELECTION CRITERIA

- *LOW MASS/VOLUME*
- *HIGH PAYLOAD FRACTION*
- *LARGE RANGE OF MOBILITY*
- *ACTIVE CONTROL*
- *IMPLEMENTATION READINESS*

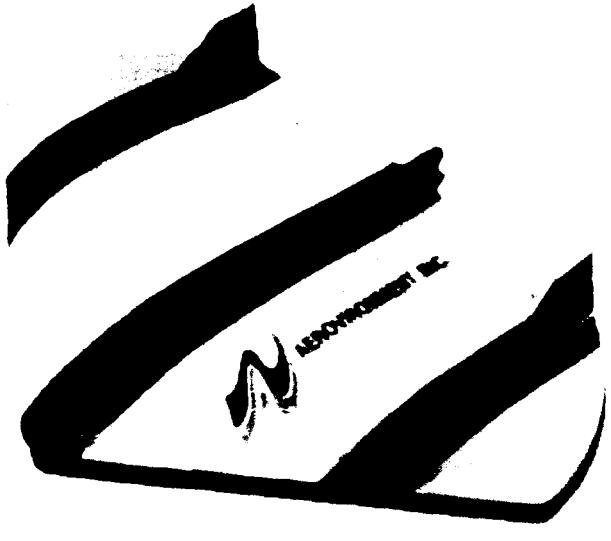
GLIDER BASELINE DESIGN CHARACTERISTICS

- *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*

sarita.thakoor@jpl.nasa.gov

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***

sarita.thakoor@jpl.nasa.gov

Biomorphic Gliders

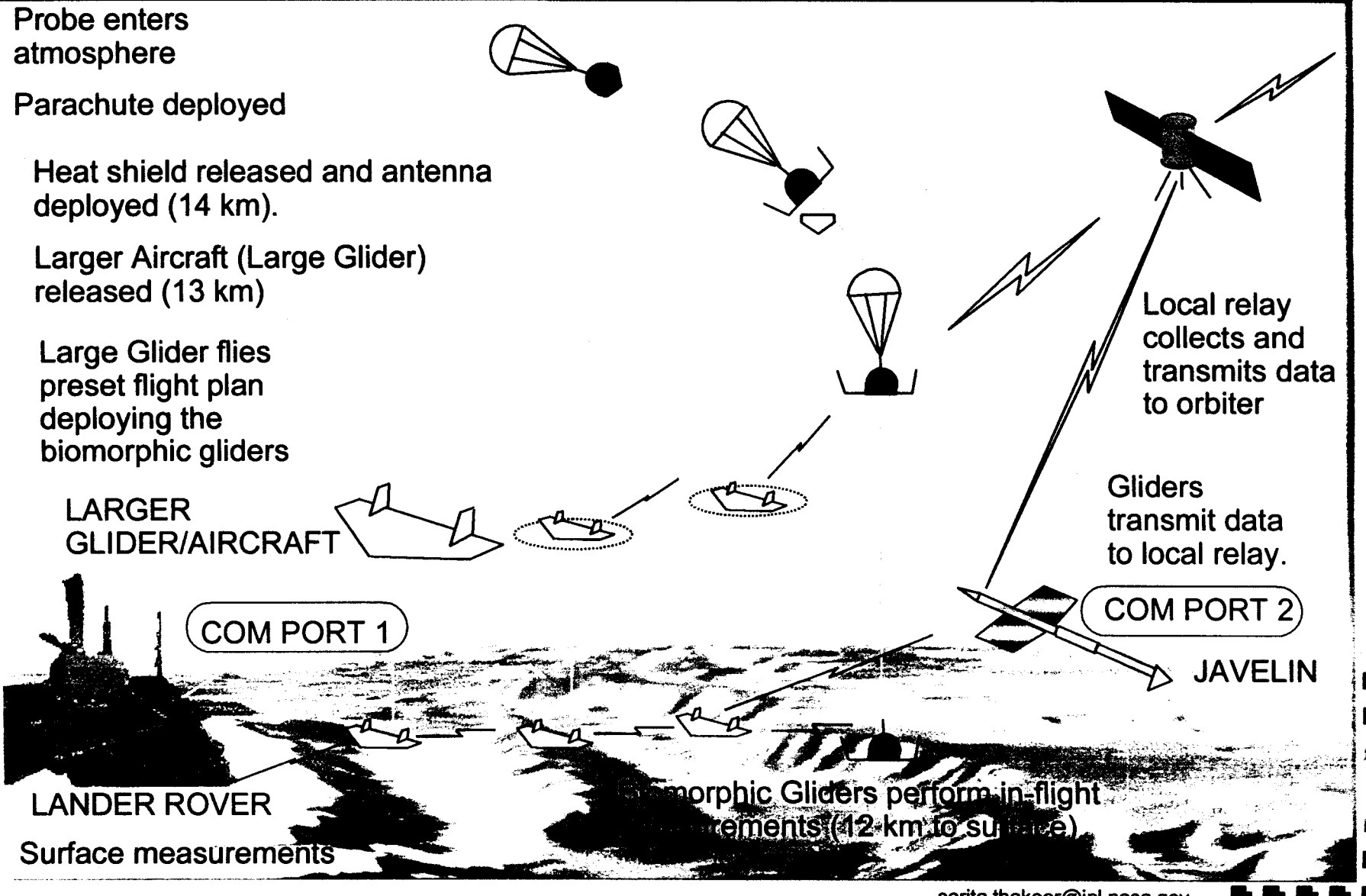
- **Small, simple, low-cost system ideal for reconnaissance and wide-area dispersion of sensors and small experiments.**
- **Payload mass fraction 50% or higher.**

		Baseline			
Total Mass (M)	=	57	75	250	500 g
Payload (P)	=	32	45	150	300 g
P/M fraction	=	56	60	60	60 %
Wing Span	=	0.19	0.25	0.50	0.76 m
Wing Area	=	0.014	0.021	0.071	0.143 m^2
Volume	=	168	300	1700	5200 cm^3
Flight Speed	=	90	90	90	90 m/s
Range	=	50	55	72	83 km
Duration	=	590	650	800	1300 s
Glide Ratio	=	5.3	5.8	7.5	8.6
Starting Alt.	=	10	10	10	10 km

- 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

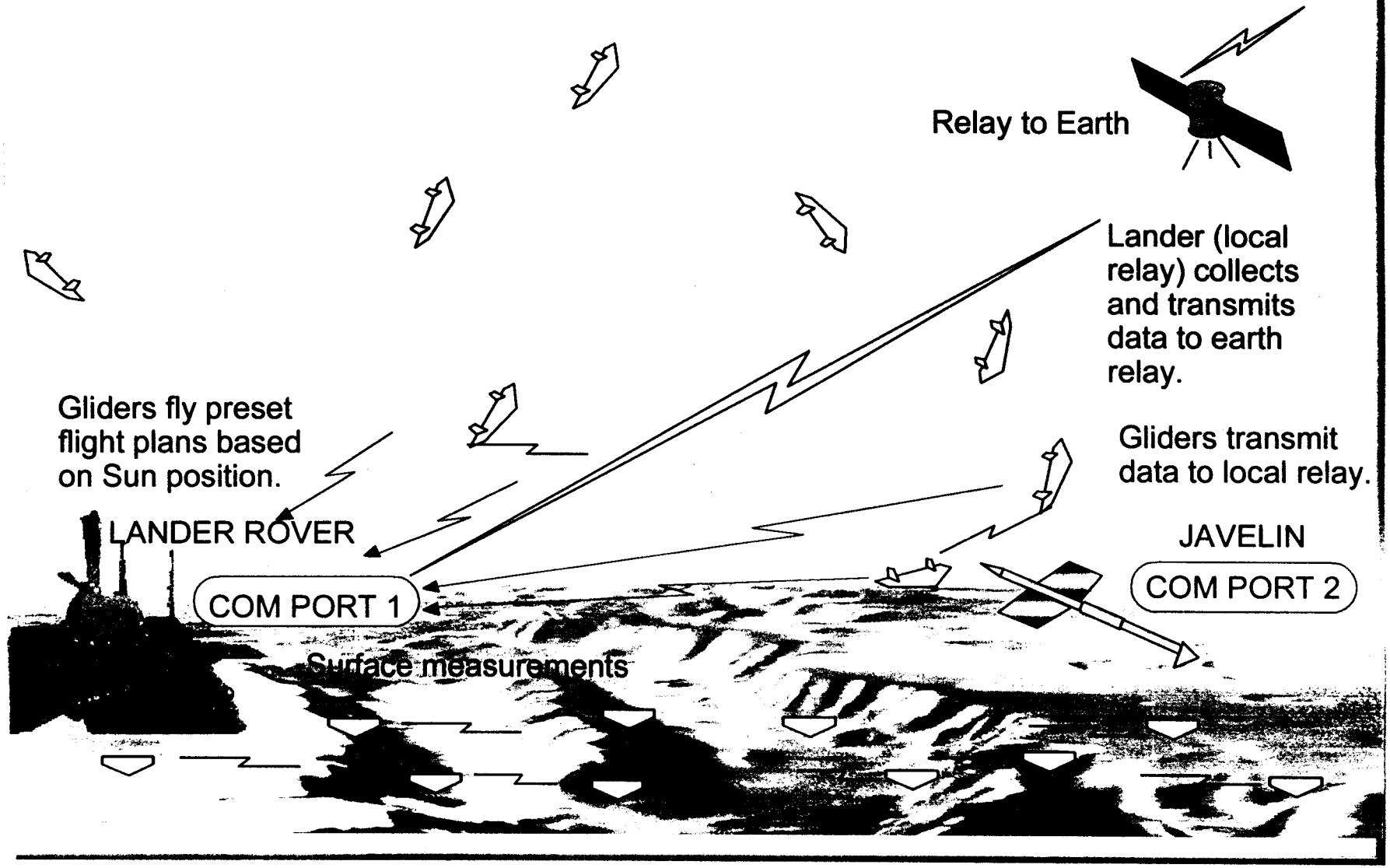
sarita.thakoor@jpl.nasa.gov

Biomorphic Glider Deployment Concept: Larger Glider Deploy/Local Relay



sarita.thakoor@jpl.nasa.gov

Biomorphic Glider Deployment Concept: Probe Deploy/Lander Relay



sarita.thakoor@jpl.nasa.gov

Biomorphic Glider Deployment/Telecommunication Concept

Probe enters atmosphere

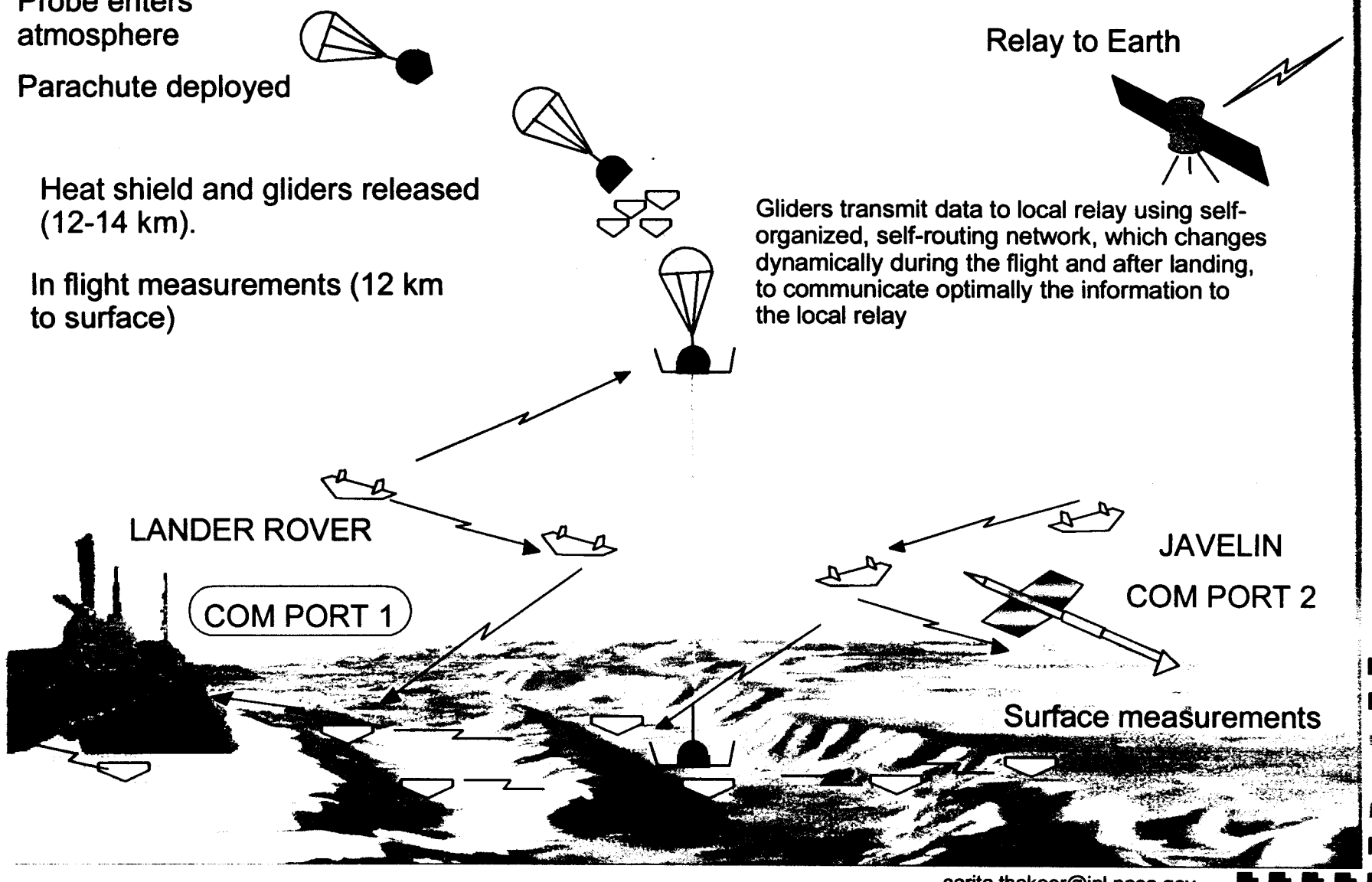
Parachute deployed

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

In flight measurements (12 km to surface)

Relay to Earth

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



sarita.thakoor@jpl.nasa.gov

SUMMARY & ROADMAP

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

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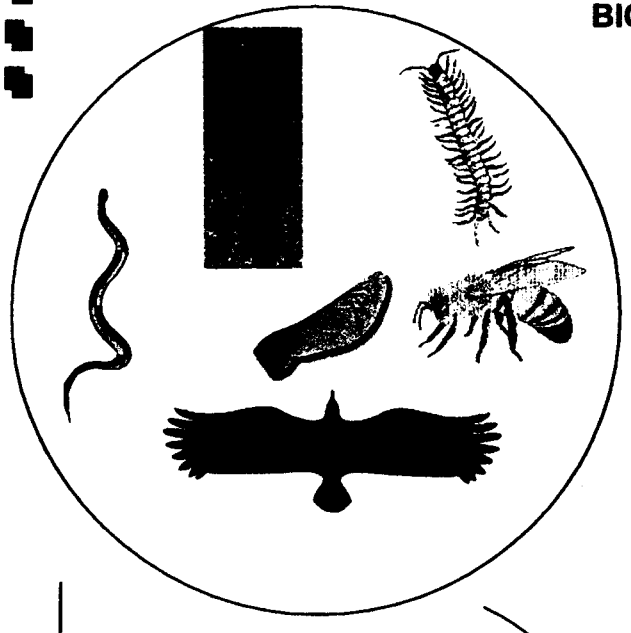
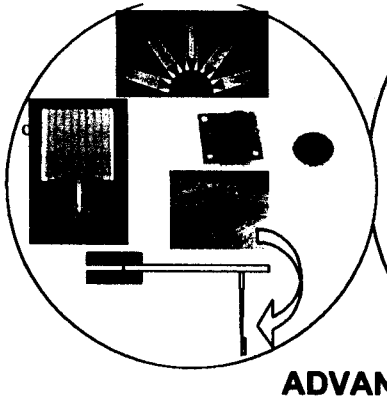
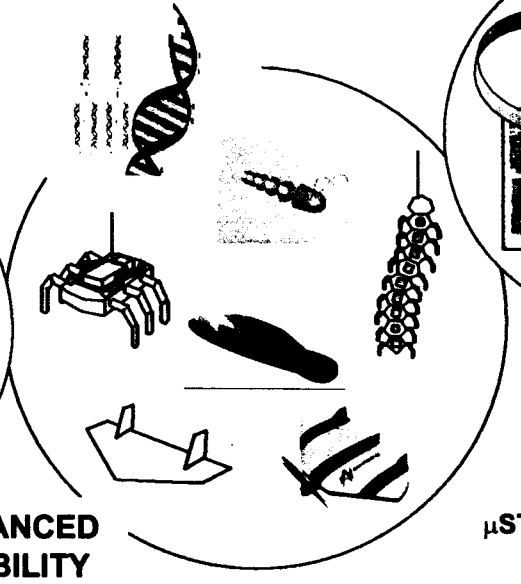
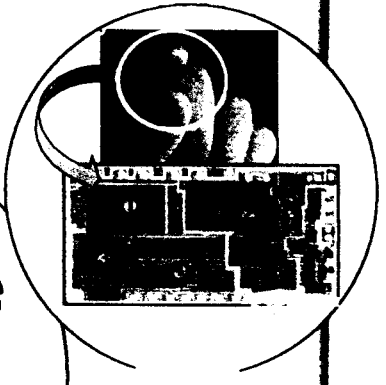
BIOMORPHIC COOPERATIVE BEHAVIOR
BIOMORPHIC CONTROL ALGORITHMS





μSENSORS





μCOMMUNICATION

TEMPERATURE CONTROL

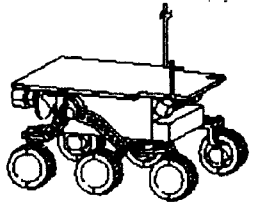
μSTRUCTURE

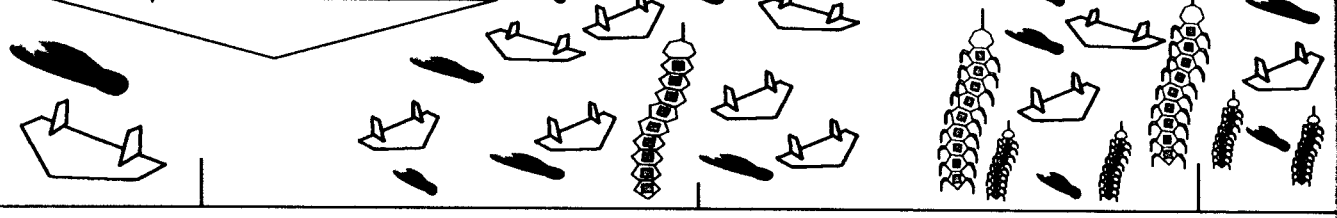
ADVANCED MOBILITY

μPOWER

μNAVIGATION

μCOMPUTING





1997 **2002** **2007** **2012?**

sarita.thakoor@jpl.nasa.gov

COORDINATED/COOPERATIVE EXPLORATION SCENARIO

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

sarita.thakoor@jpl.nasa.gov

Applications

- Distributed Aerial Measurements
  - Ephemeral 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

sarita.thakoor@jpl.nasa.gov

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

sarita.thakoor@jpl.nasa.gov