Mars Exploration Using Biomorphic Flyers

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Javaan Chahl, M.V. Srinivasan: Australian National Univ, Canberra, Australia;
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ABSTRACT

Autonomous robotic systems will be essential for the exploration of Mars and other planetary systems. Borrowing from nature to implement biologically inspired capabilities in robotic systems is one approach to achieving autonomy. This project is considering biological features and capabilities derived from three separate species; the dragonfly, the bumblebee and the rabbit. By reverse engineering and blending nature's solutions to orienting and navigating in the physical world, we are demonstrating the power of this approach for future robotic explorers.

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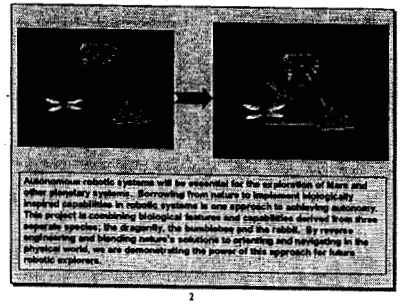

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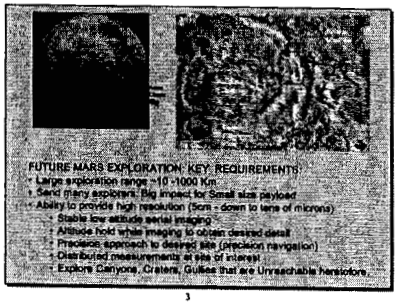

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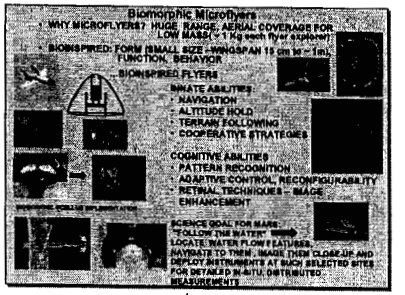

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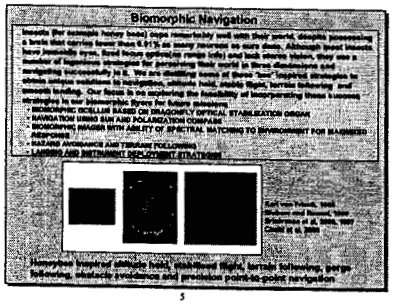

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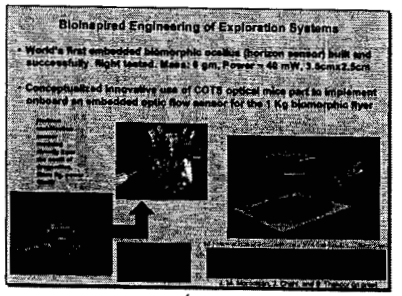

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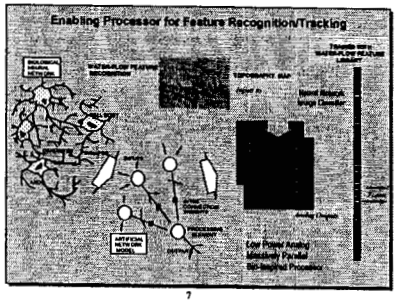

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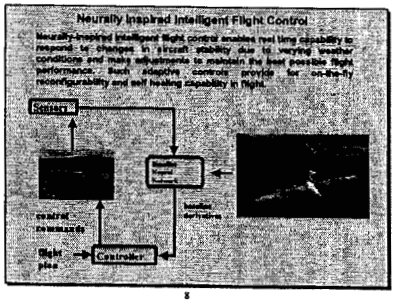

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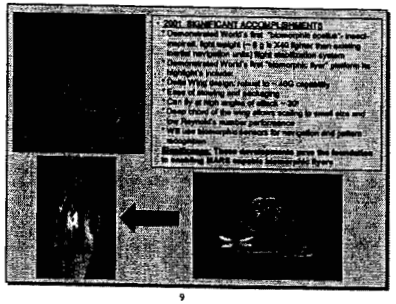

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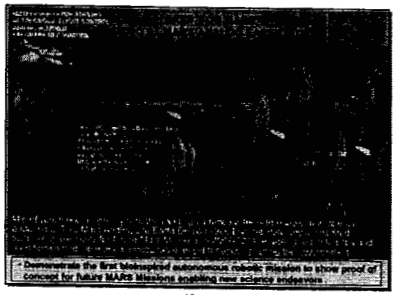

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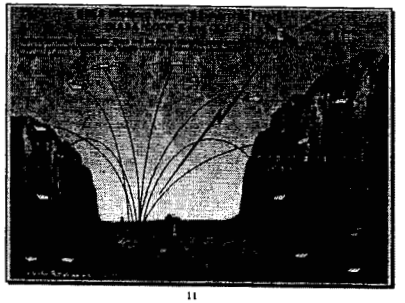

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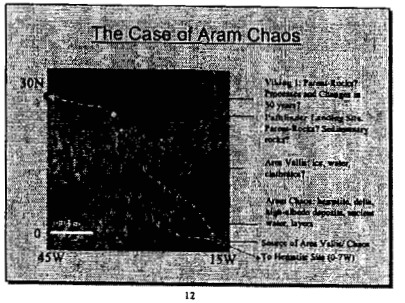

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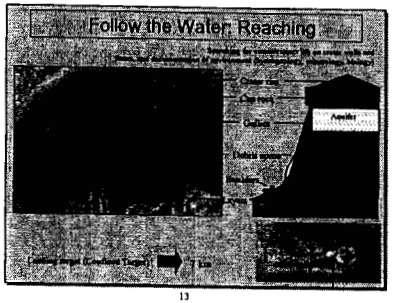

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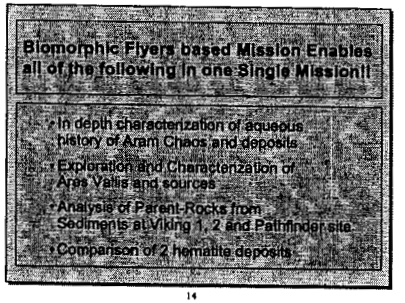

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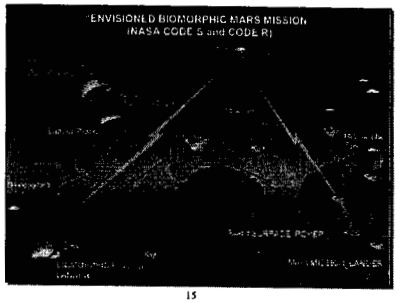

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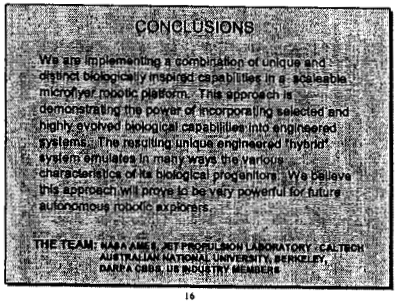

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ABSTRACT

Mars imagery obtained by the Mariner, Viking, Pathfinder, Mars Global Surveyor and Mars Odyssey Missions suggests the previous existence of abundant liquid water (considered essential for life as we know it). It is not clear what transpired on the Martian climate to have turned the planet in to the desert that it is today. Developing a comprehensive understanding of the past and present climatic events for our sister planet Mars may provide important information relevant to the future health and well being of our own planet. Following and exploring water flow features is a valuable strategy in the search for extant or extinct life, it satisfies our fundamental scientific curiosity, and could provide answers to the fundamental questions surrounding the question of the origins of life in our solar system. Low altitude air-borne exploration of Mars offers a means for covering large areas, perhaps up to several hundred kilometers, quickly and efficiently. Aerial exploration should provide a close-up birds eye view of the planetary terrain. Exploration that can only be imagined today could become a reality if we develop methods to fly on Mars and navigate through its difficult terrain to image/study sites of interest. Mars offers a substantial challenge to conventional flight due to its thin atmosphere (about a hundredth that on Earth); lack of magnetic compassing for navigation, and the limited telecommunications or navigational infrastructure. To meet and overcome these challenges, we are adapting for Mars exploration principles proven successful in nature to achieve stable flight control and navigation. By incorporating engineering solutions modeled on successful biological solutions we will provide novel and highly effective micro flyer capabilities suitable for aerial surveillance of Mars. We describe here an example site on Mars whose exploration absolutely requires the ability to cover several hundred kilometers. We will illustrate how autonomous biomorphic flyers will enable imagery and environmental measurements to be captured from extremely low altitudes and even inside terrain features such as canyons that were previously considered impossible to explore on a large scale. At a Terrestrial analog Martian site, we plan to demonstrate a proof of concept simulation experiment, emulating selected conditions of Mars. The demonstration will consist of launching/deploying a variety of biomorphic flyers each containing biologically inspired technologies capable of, for example, autonomous real time navigation, visual search, selective feature detection, intelligent flight control and image enhancement by sensory data fusion.

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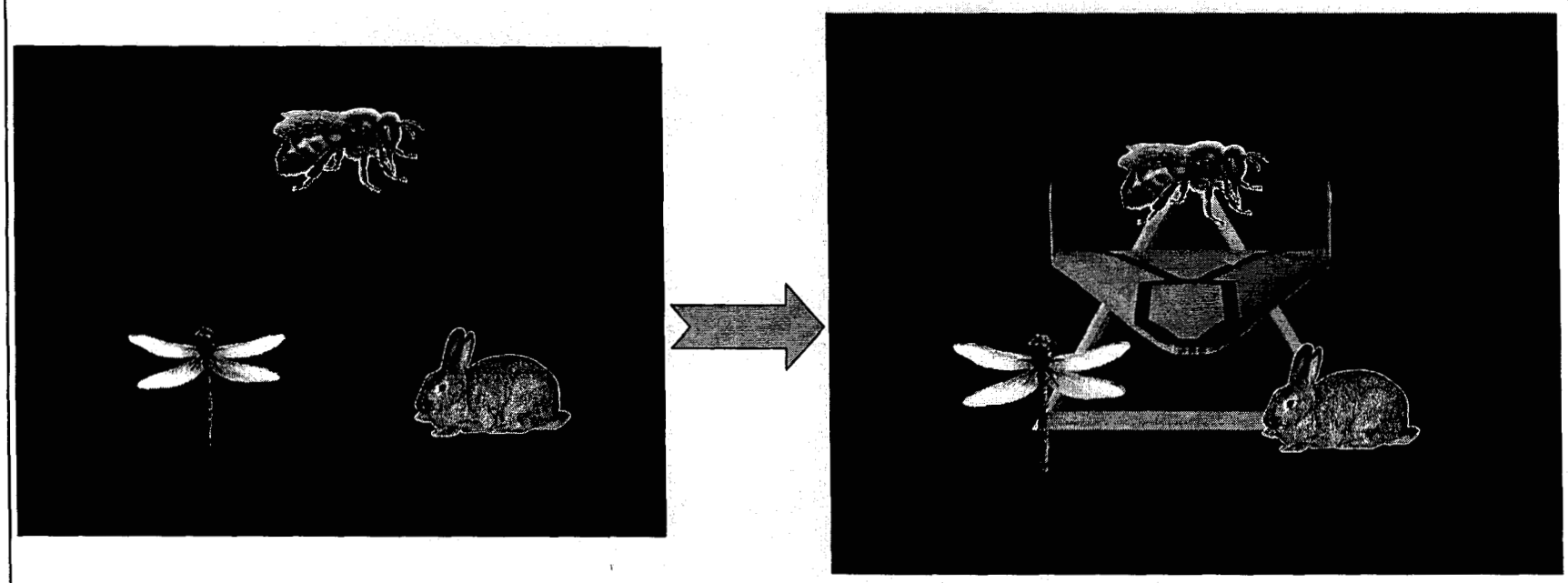
BIOINSPIRED ENGINEERING OF EXPLORATION SYSTEMS



Autonomous robotic systems will be essential for the exploration of Mars and other planetary systems. Borrowing from nature to implement biologically inspired capabilities in robotic systems is one approach to achieving autonomy. This project is combining biological features and capabilities derived from three separate species; the dragonfly, the bumblebee and the rabbit. By reverse engineering and blending nature's solutions to orienting and navigating in the physical world, we are demonstrating the power of this approach for future robotic explorers.

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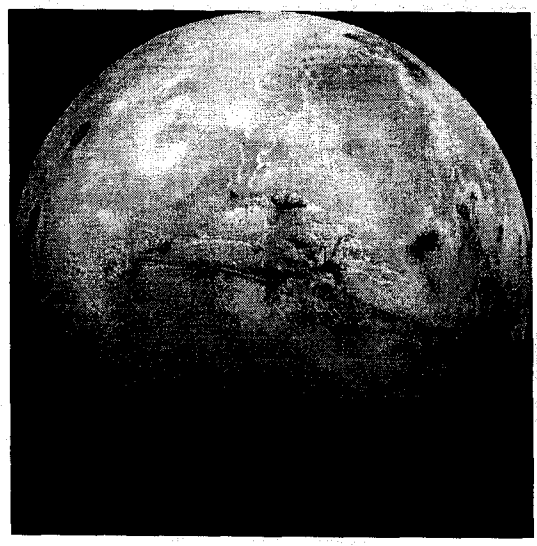
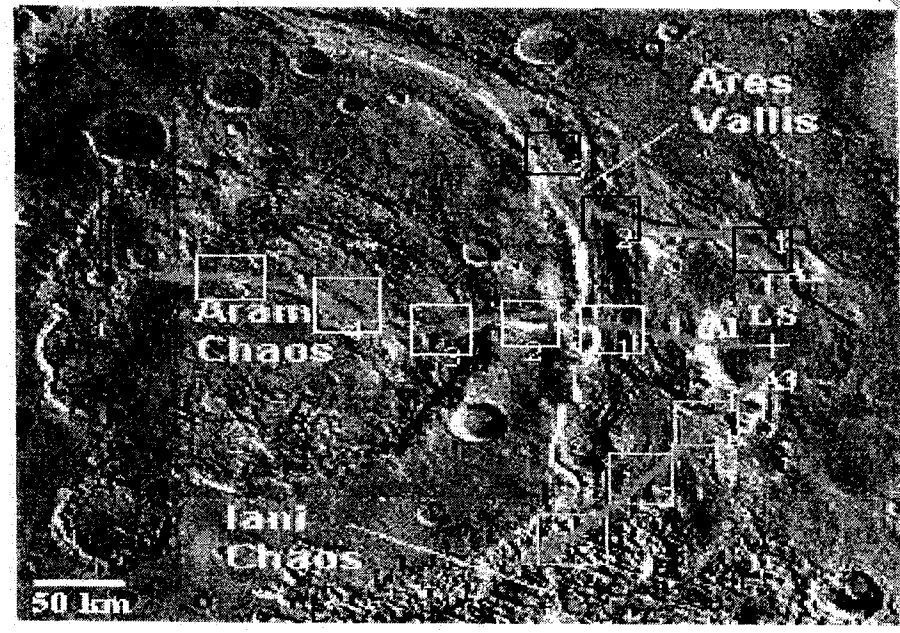


Aram Chaos Site



FUTURE MARS EXPLORATION: KEY REQUIREMENTS:

- Large exploration range ~10 -1000 Km
- Send many explorers: Big impact for Small size payload
- Ability to provide high resolution (5cm - down to tens of microns)
  - Stable low altitude aerial imaging
  - Altitude hold while imaging to obtain desired detail
  - Precision approach to desired site (precision navigation)
  - Distributed measurements at site of interest
  - Explore Canyons, Craters, Gullies that are Unreachable heretofore.

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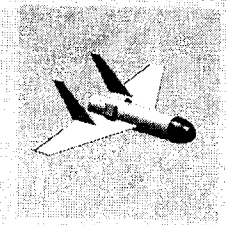
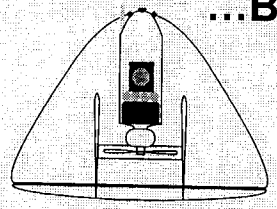
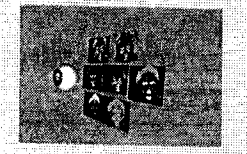
Biomorphic Microflyers

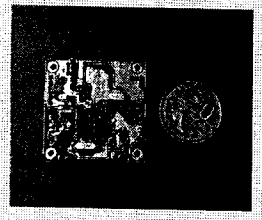
- WHY MICROFLYERS? HUGE RANGE, AERIAL COVERAGE FOR LOW MASS(~ 1 Kg each flyer explorer)
- BIOINSPIRED: FORM (SMALL SIZE –WINGSPAN 15 cm to ~ 1m), FUNCTION, BEHAVIOR

...BIOINSPIRED FLYERS

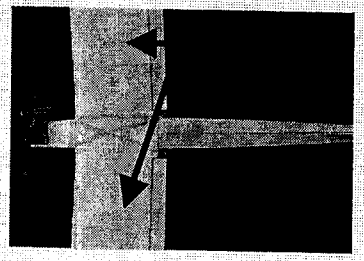




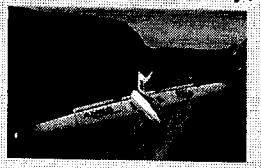


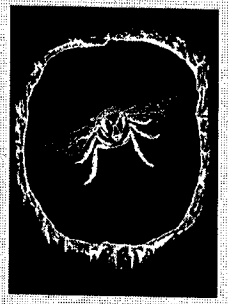


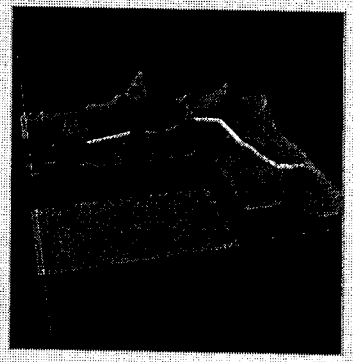
BIOMORPHIC OCELLUS IMPLEMENTATION



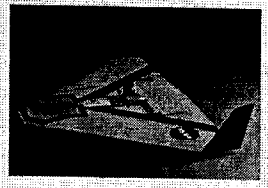
INNATE ABILITIES:
- NAVIGATION
- ALTITUDE HOLD
- TERRAIN FOLLOWING
- COOPERATIVE STRATEGIES







COGNITIVE ABILITIES
- PATTERN RECOGNITION
- ADAPTIVE CONTROL, RECONFIGURABILITY
- RETINAL TECHNIQUES – IMAGE ENHANCEMENT



SCIENCE GOAL FOR MARS:
"FOLLOW THE WATER"
LOCATE WATER FLOW FEATURES, NAVIGATE TO THEM , IMAGE THEM CLOSE-UP AND DEPLOY INSTRUMENTS AT SUCH SELECTED SITES FOR DETAILED IN-SITU, DISTRIBUTED MEASUREMENTS

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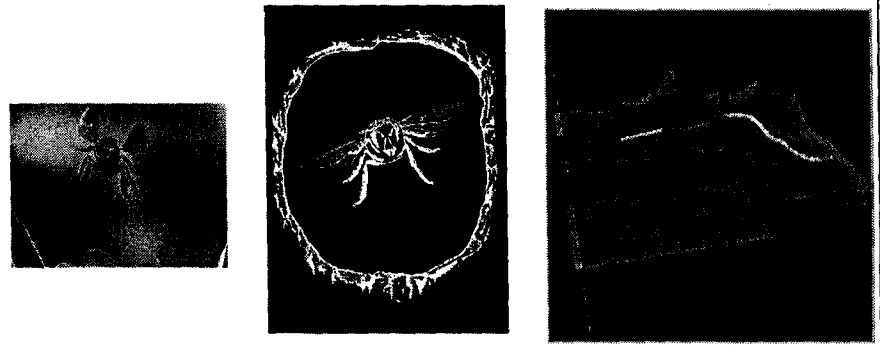
Biomorphic Navigation

Insects (for example honey bees) cope remarkably well with their world, despite possessing a brain that carries fewer than 0.01% as many neurons as ours does. Although most insects have immobile eyes, fixed focus optics(no range info) and lack stereo vision, they use a number of ingenious strategies for perceiving their world in three dimensions and navigating successfully in it. We are distilling some of these 'bee' inspired strategies to obtain unique solutions to navigation, altitude hold, stable flight, terrain following and smooth landing. Our focus is on exploring the feasibility of incorporating these success strategies in our biomorphic flyers for future missions

- BIOMORPHIC OCELLUS BASED ON DRAGONFLY OPTICAL STABILIZATION ORGAN
- NAVIGATION USING SUN AND POLARIZATION COMPASS
- BIOMORPHIC IMAGER WITH ABILITY OF SPECTRAL MATCHING TO ENVIRONMENT FOR MAXIMIZED RESPONSE
- HAZARD AVOIDANCE AND TERRAIN FOLLOWING
- LANDING AND INSTRUMENT DEPLOYMENT STRATEGIES



Karl von Frisch, 1965
Wehner and Rossel, 1985
Srinivasan et al, 2000, 1997
Chahl et al, 2000

Honeybee Inspired altitude hold, stabilised flight, terrain following, gorge following, obstacle avoidance and precision point-to-point navigation

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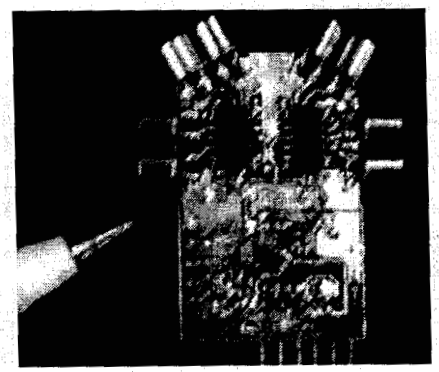
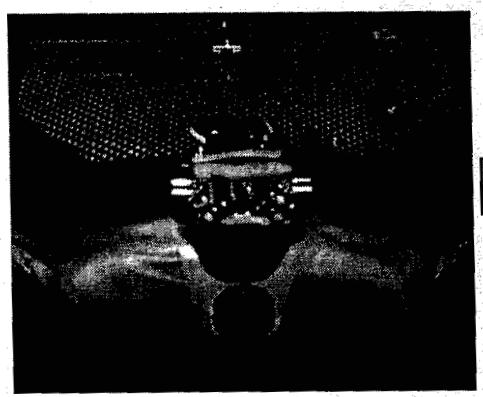
Bioinspired Engineering of Exploration Systems

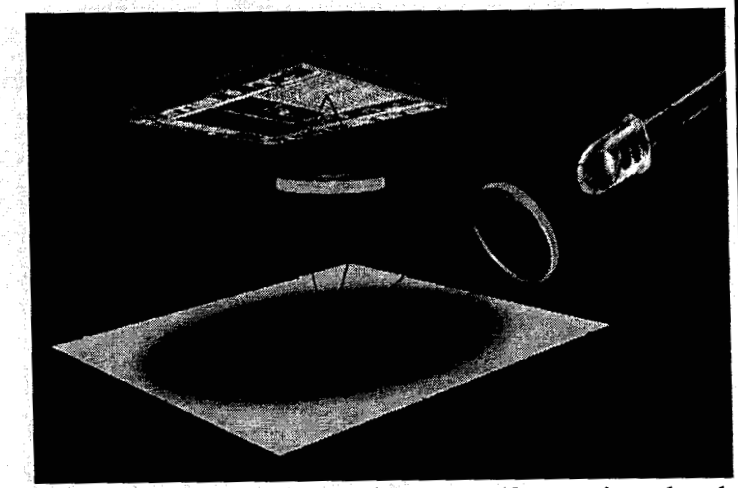
- World's first embedded biomorphic ocellus (horizon sensor) built and successfully flight tested. Mass: 6 gm, Power ~ 40 mW, 3.5cmx2.5cm

- Conceptualized innovative use of COTS optical mice part to implement onboard an embedded optic flow sensor for the 1 Kg biomorphic flyer

Horizon stabilization sensor modeled directly from the ocelli of dragonflies. Mass 6g, power 40mW







http://www.labs.agilent.com/news/2001features/fea_optinav.html

J. M. Morookian, J. Chahl, and S. Thakoor (in prep)

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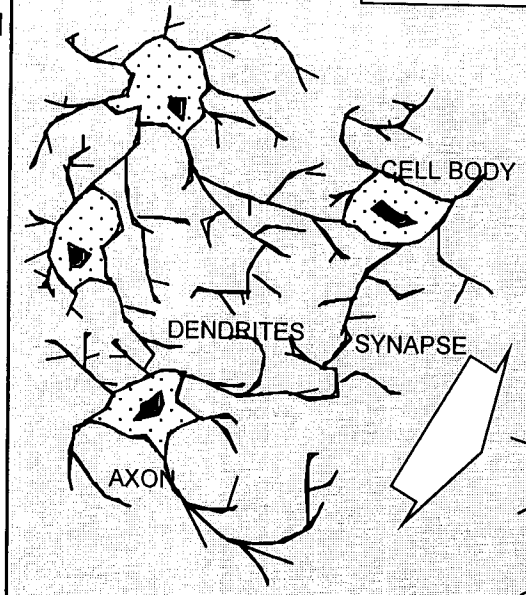
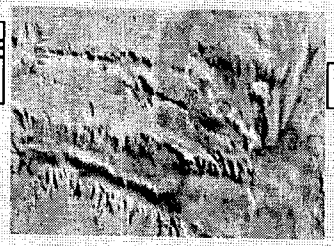
Enabling Processor for Feature Recognition/Tracking

BIOLOGICAL NEURAL NETWORK



WATER-FLOW FEATURE RECOGNITION



TOPOGRAPHY MAP

Input to

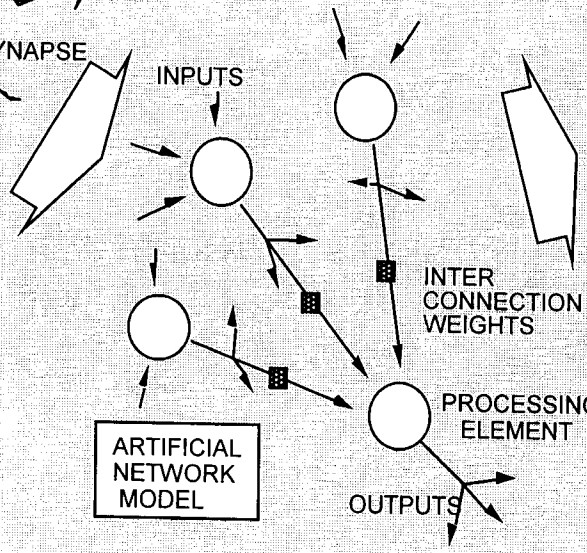
Neural Network Image Classifier

TRAINED WITH WATER-FLOW FEATURE LIBRARY

CNN/ANN Image Processor

Analog Outputs

Identified Feature



Low Power Analog
Massively Parallel
Bio-Inspired Processor

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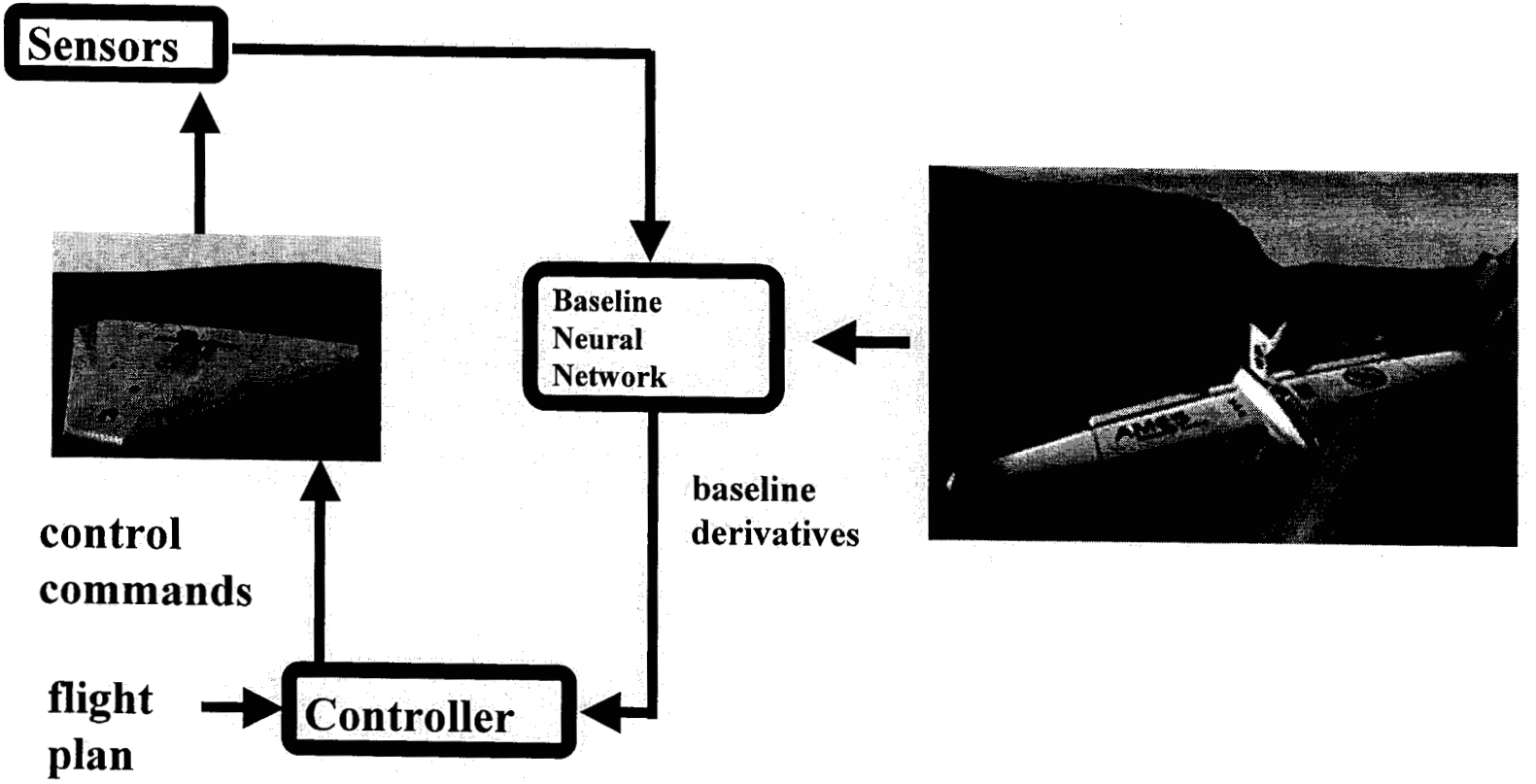
Neurally Inspired Intelligent Flight Control

Neurally-inspired intelligent flight control enables real time capability to respond to changes in aircraft stability due to varying weather conditions and make adjustments to maintain the best possible flight performance. Such adaptive controls provide for on-the-fly reconfigurability and self healing capability in flight.



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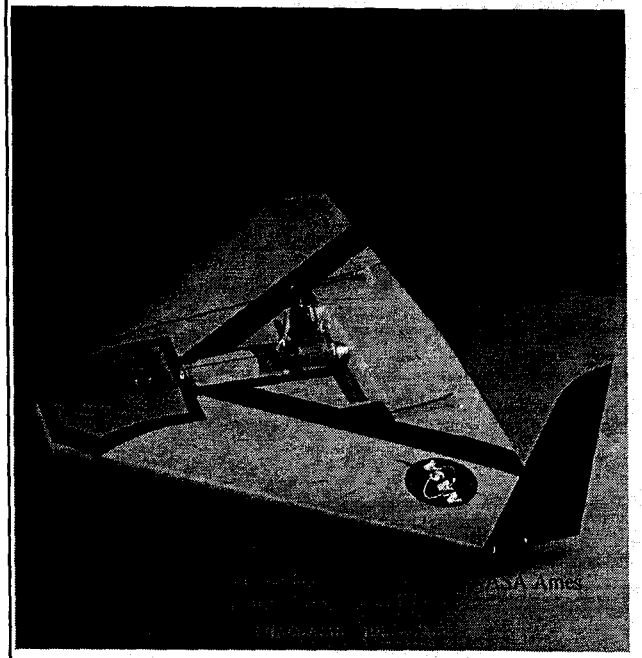


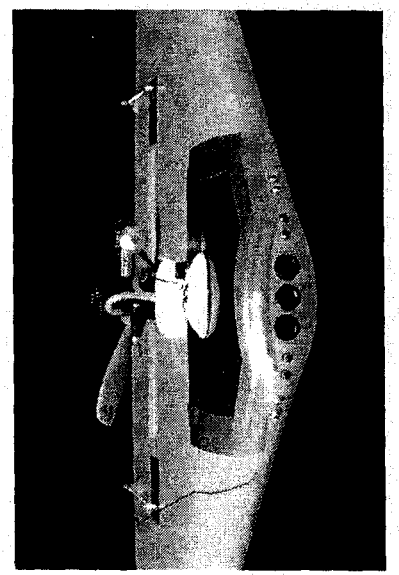
• 2001 SIGNIFICANT ACCOMPLISHMENTS

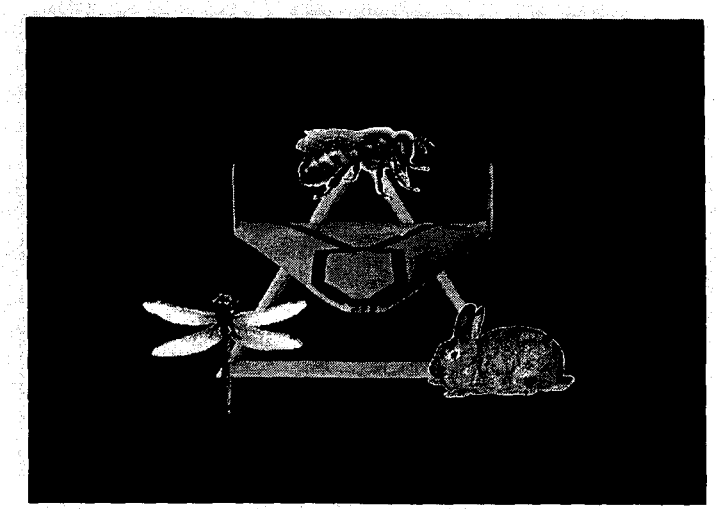
* Demonstrated World's first "biomorphic ocellus"- insect-inspired, light weight (~ 6 g is X40 lighter than existing inertial navigation units) flight stabilization system

* Demonstrated World's first "biomorphic flyer" platform Its highlight's include:

* Delta Wing design : robust to ~ 40G capability
* Ease of stowing and packaging
* Can fly at high angles of attack ~ 30°
* Deep chord of the wing allows scaling to small size and low Reynold's number performance
* Will use biomorphic sensors for navigation and pattern recognition

Significance: These developments pave the foundation to enabling MARS capable biomorphic flyers





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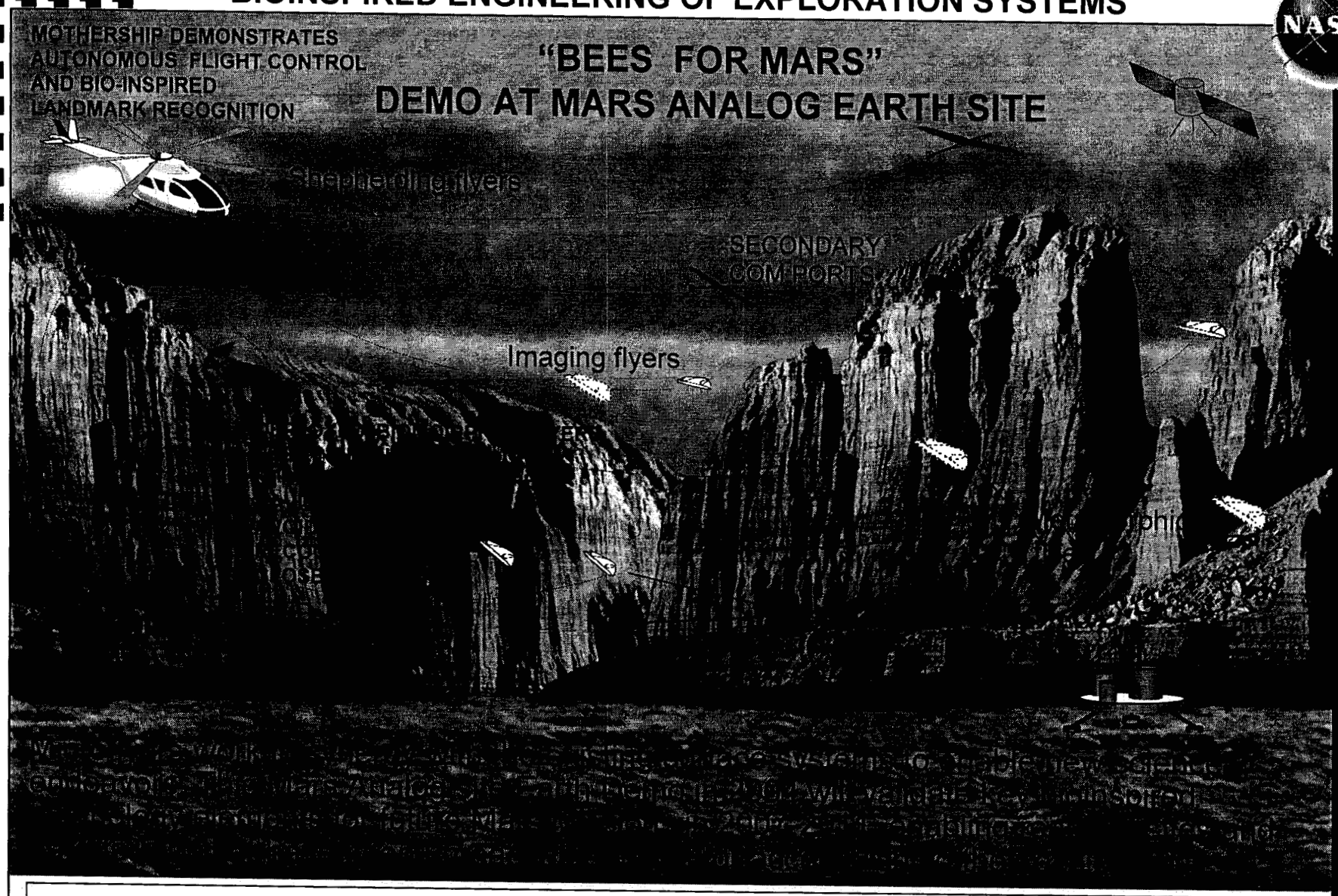

- Demonstrate the first bioinspired autonomous robotic mission to show proof of concept for future MARS Missions enabling new science endeavors

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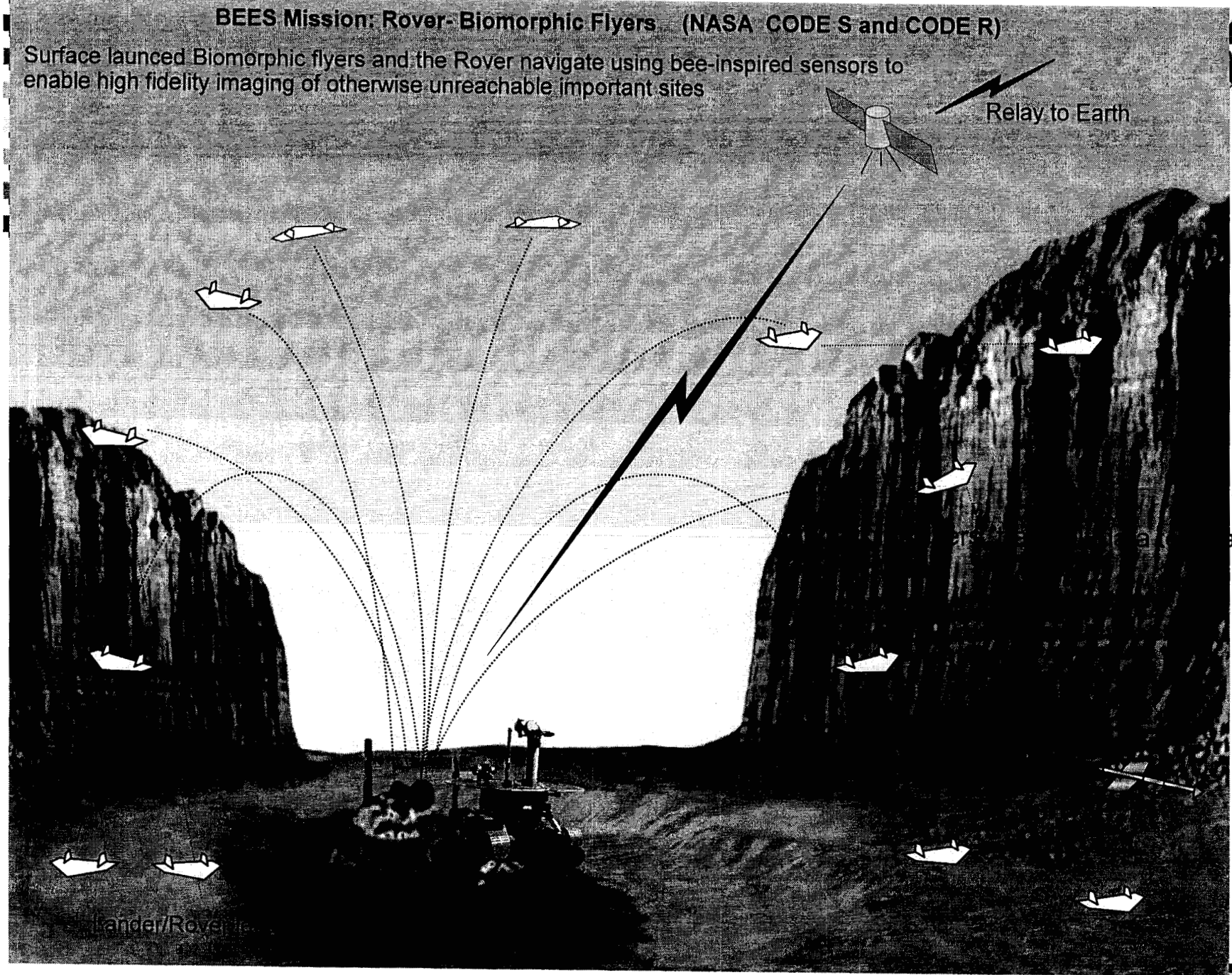
BEES Mission: Rover- Biomorphic Flyers (NASA CODE S and CODE R)

Surface launced Biomorphic flyers and the Rover navigate using bee-inspired sensors to enable high fidelity imaging of otherwise unreachable important sites



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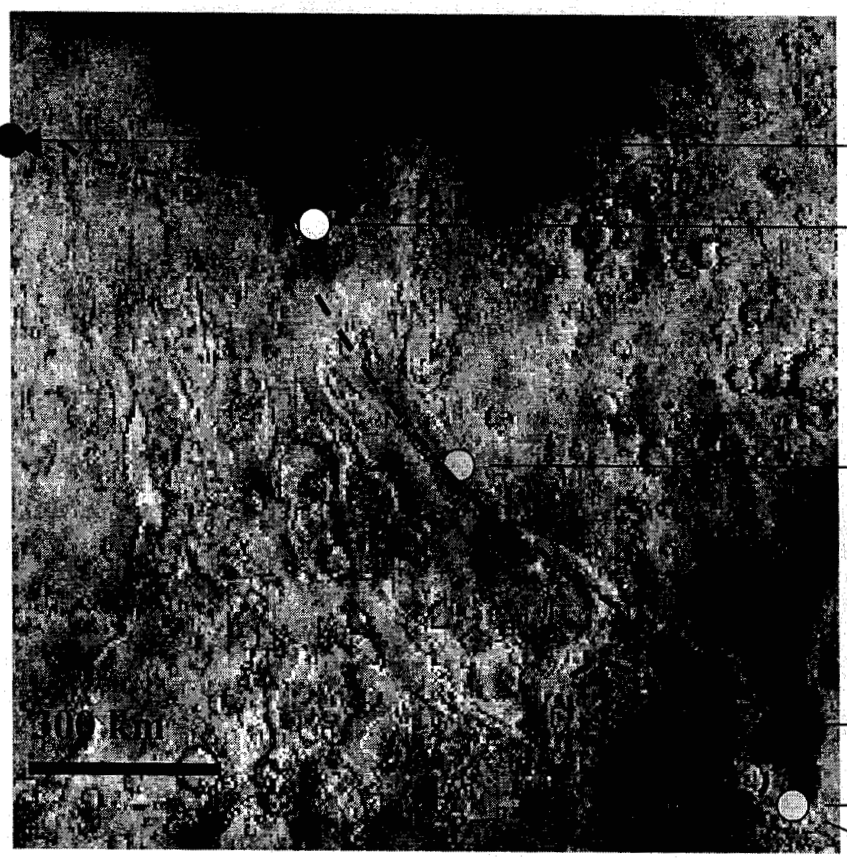
The Case of Aram Chaos



Viking 1: Parent-Rocks? Processes and Changes in 30 years?

Pathfinder Landing Site. Parent-Rocks? Sedimentary rocks?

Ares Vallis: ice, water, clathrates?

Aram Chaos: hematite, delta, high-albedo deposits, ancient water, layers

Source of Ares Vallis/ Chaos

To Hematite Site (0-7W)

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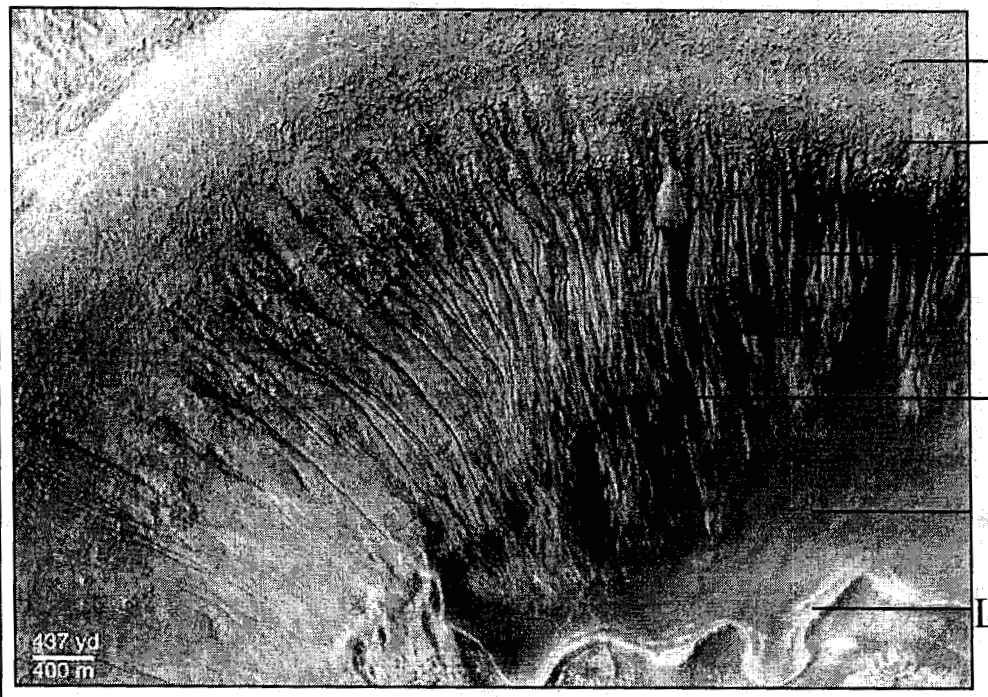
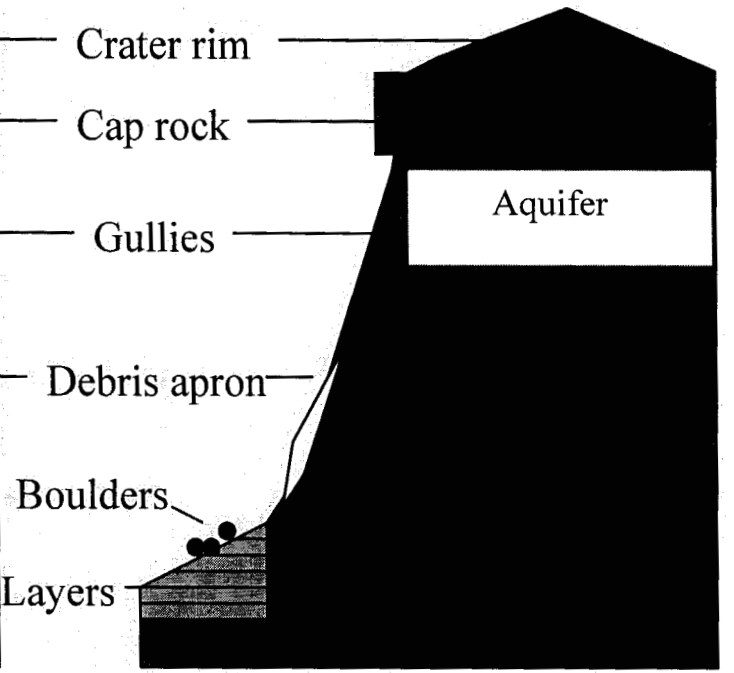
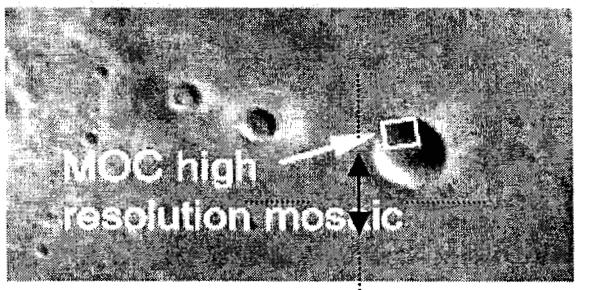
Follow the Water: Reaching

Searching for extant/extinct life on crater walls and floors, and documentation of environment (hydrogeology, mineralogy, biology)





Landing target (Confined Target) → 7 km



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Biomorphic Flyers based Mission Enables all of the following in one Single Mission!!

- In depth characterization of aqueous history of Aram Chaos and deposits
- Exploration and Characterization of Ares Vallis and sources
- Analysis of Parent-Rocks from Sediments at Viking 1, 2 and Pathfinder site
- Comparison of 2 hematite deposits

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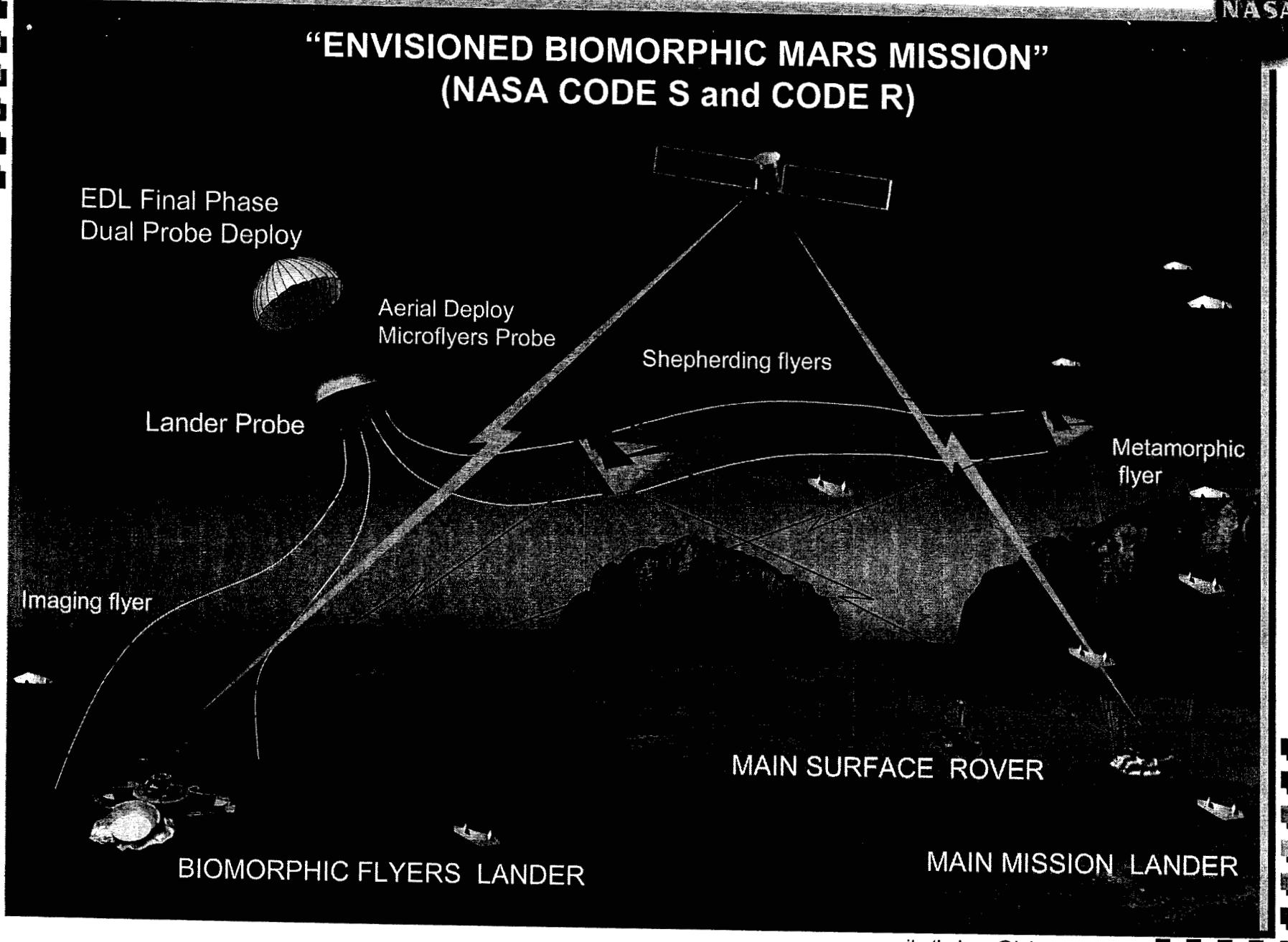
"ENVISIONED BIOMORPHIC MARS MISSION" (NASA CODE S and CODE R)



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CONCLUSIONS

We are implementing a combination of unique and distinct biologically inspired capabilities in a scaleable microflyer robotic platform. This approach is demonstrating the power of incorporating selected and highly evolved biological capabilities into engineered systems. The resulting unique engineered "hybrid" system emulates in many ways the various characteristics of its biological progenitors. We believe this approach will prove to be very powerful for future autonomous robotic explorers.

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