Bioinspired Engineering of Exploration Systems (BEES) – Its Impact on Future Missions

Sarita Thakoor*
Jet Propulsion Laboratory, CalTech, Pasadena, CA 91109

Butler Hine†, and Steve Zornetzer‡
NASA, AMES Research Center, Moffet Field, CA 94035

This paper describes an overview of our "Bioinspired Engineering of Exploration Systems for Mars" ("BEES for Mars") project. The BEES approach distills selected biologically inspired strategies utilizing motion cues/optic flow, bioinspired pattern recognition, biological visual and neural control systems, bioinspired sensing and communication techniques, and birds of prey inspired search and track algorithmic systems. Unique capabilities so enabled, provide potential solutions to future autonomous robotic space and planetary mission applications. With the first series of tests performed in September 2003, August 2004 and September 2004, we have demonstrated the BEES technologies at the El Mirage Dry Lakebed site in the Mojave Desert using Delta Wing experimental prototypes. We call these test flyers the "BEES flyer", since we are developing them as dedicated test platform for the newly developed bioinspired sensors, processors and algorithmic strategies. The Delta Wing offers a robust airframe that can sustain high G launches and offers ease of compact stowability and packaging along with scaling to small size and low Reynold's number performance for a potential Mars deployment. Our approach to developing light weight, low power autonomous flight systems using concepts distilled from biology promises to enable new applications, of dual use to NASA and DoD needs. Small in size (0.5 -5 Kg) BEES Flyers are demonstrating capabilities for autonomous flight and sensor operability in Mars analog conditions. The BEES project team spans JPL, NASA Ames, Australian National University (ANU), Brigham Young University(BYU), UC Berkeley, Analogic Computers Inc. and other institutions. The highlights from our recent flight demonstrations exhibiting new Mission enabling capabilities are described. Further, this paper describes two classes of potential new missions for Mars exploration: (1) the long range exploration missions, and (2) observation missions, for real time imaging of critical ephemeral phenomena, that can be enabled by use of BEES flyers. For example, such flyers can serve as a powerful black-box for critical descent and landing data and enablers for improved science missions complementing and supplementing the existing assets like landers and rovers by providing valuable exploration and quick extended low-altitude aerial coverage of the sites of interest by imaging them and distributing instruments to them. Imaging done by orbiters allows broad surface coverage at limited spatial resolution. Low altitude air-borne exploration of Mars offers a means for imaging large areas, perhaps up to several hundred kilometers, quickly and efficiently, providing a close-up birds-eye view of the planetary terrain and close-up approach to constrained difficult areas like canyons and craters. A novel approach to low-mass yet highly capable flyers is enabled by small aircraft equipped using sensors and processors and algorithms developed using BEES technology. This project is focused towards showing the direct impact of blending the best of artificial intelligence attributes and bioinspiration to create a leap beyond existing capability for our future Missions.

* Manager, "BEES for Mars" NASA Ames-JPL Joint Project, MS T1710, Senior Member AIAA.
† Program Manager, CICT, NASA Ames, Mail Stop 258-3
‡ Deputy Director for Research, NASA Ames, Mail Stop I:200-3

I. Introduction

THE goal of the "Bioinspired Engineering of Exploration Systems for Mars" ("BEES for Mars") project is to demonstrate the impact of bioinspired technologies by an early proof of concept demonstration of selected bioinspired technologies. The demonstrations utilize minimal infrastructure and computational resources, emulate the strategies distilled from biological flyers (insects and birds) for visual motion cues/optic flow, bioinspired pattern recognition, biological visual and neural control systems, bioinspired sensing and communication techniques and birds of prey inspired search and track algorithmic systems. As described earlier[1-9], the intent of BEES is to accomplish new capabilities by extracting the salient principles from a variety of diverse organisms well adept at that specific capability. Recently, many workshops and conferences[10] including the BEES 2000 conference[11], have featured bioinspired technologies, as have many publications[12] for implementing some of these technologies. The "BEES for Mars" project is managed by NASA-JPL with programmatic oversight from NASA –Ames. The technical research areas in development within the project are primarily as follows:

1. Bioinspired navigation suite development at the Australian National University (ANU) and JPL
2. Bioinspired recognition and motion estimation visual processor development at Analogic Inc and University of California, Berkeley, and JPL
3. Bioinspired Search and Track Algorithms and development of Observation/Imaging Mission demo at the Brigham Young Univ, and JPL
4. Bioinspired Adaptive control and Mars capable airframe aerodynamic studies being conducted at NASA AMES
5. Bioinspired design of communication elements including antenna design conducted at NASA Ames and JPL

This paper provides an overview of the work accomplished in the project and details on the Observation/Imaging Mission. The field site used for the demonstrations to simulate some of the Mars representative analog features is described along with the key features it provides. The bioinspired navigation work, the recognition/motion estimation work in development of a compact visual microprocessor, and Mars aerodynamics work along with adaptive control studies is described in further detail in companion papers in this proceedings by J. Chahl et al[13], C. Rekeczky et al[14] and K. Kumar et al[15] respectively. This paper describes the overview of this project and details the recent demonstration flights performed in September 04 illustrating the mission impact of the development of the bioinspired attributes for an Observation Mission. It itemizes further research areas in the BEES domain that form a composite to enable future Mars Missions. BEES technology is particularly an enabler for two classes of Missions, the Observation Missions and Long Range Exploration Missions as described in this paper.

II. Field Test Site: El Mirage Dry Lake Bed

The features of El Mirage as a field test site that are ideal include the presence of a dry lake bed stretch about 3km wide and ~ 10 Km in length, a minimal hazard low shrub area and then a stretch of taller Joshua trees and at the outskirts the rolling Shadow mountains. This combination allows system testing of basic sensor, processor and algorithm operations in a safe flat dry lake bed, to hardier testing of hazard avoidance and terrain following capabilities with a variation of hazard levels as well as a stretch of smooth rolling hills for terrain following tests all in the same setting. Geologically and scientifically it offers a rich ensemble of characteristics that can be studied. For flight field test operations, the dry lake bed is an excellent launch base. For communications, the environment was tested and found to be completely free of RF noise interference particularly at the communication frequencies of 900Mhz and 2.4GHz being used for data and video communication respectively, because this desert site is far away from any habitation or other business establishments. The typical elevation of this field area is ~ 2800ft in the flat lake bed area.

Figure 1a shows a photograph of the field site as seen from the flat lake bed area launch base in the Gyrocopter Cove area of the El Mirage Dry Lake Bed. This photograph shows the surfacial cracks and hummocks with shrubs growing on them and further away shows the neighboring rolling hills of the Shadow mountains with the prominent little hill called "Resurrectuion Hill" in between, which holds potential to serve operationally as a good adhoc high altitude (~ 100-150m) tall midway telecom base for testing of beyond line of sight communications from the lake bed launch site. Figure 1b and 1c show respectively magnified views of the resurrection hill. Figure 2 shows a topographic map of the El Mirage site with some of the important sites marked, with their respective GPS co-ordinates.

**Figure 1. (a) A photograph of the El Mirage field site taken from the launch base.
(b) Expanded view, showing pathway to the Resurrection Hill which can serve as a good telecom relay base at a higher altitude. (c) Another expanded close-up view of the Resurrection Hill.**

Figure 2. Topographic Map of the El Mirage Dry Lake Bed area extracted from National Geographic CA USGS Topo Maps, showing the areas we scouted for our tests marked on it with their respective GPS co-ordinates.

Sites coordinates (WGS84):

Name	North	West
1) Resurrection Hill	N 34° 40.131	W 117° 36.271
2) Hess Ranch Site	N 34° 40.104	W 117° 36.320
3)) Gyrocopter Cove primary launch base	N 34° 39.752	W 117° 36.997
4) Bella Vista	N 34° 37.403	W 117° 32.396

Figure 3 shows an assortment of interesting features including (a) surfacial dessication cracks (b) drainage patterns (c) potholes (d) Joshua trees and (e), (f) wash patterns which are present at this site and provide a rich ensemble of material for scientific investigations in the future. The wash patterns are particularly from the Bella Vista area of this field test site. The Hess Ranch site is a possible secondary launch base location.

Figure 3. Examples of scientific interest features prevalent at the El Mirage site. (a) surfacial dessication cracks (b) drainage patterns (c) potholes (d) Joshua trees (e), (f) wash patterns.

III. Bioinspired Navigation: BEES-ANU/NASA-JPL Demonstration

Within this demonstration effort the focus is on development of a bioinspired navigation sensor suite that will allow operations without GPS and magnetic compass , two aids that are not readily available on Mars [1-9]

As described earlier[3-9] in detail, primarily, two types of flyers have been constructed (1) the shepherding flyers which serve a dual role as aerial telecom hubs as well as imager/instrument distribution agents and (2) the imaging flyers dedicated to provide imagery of the new areas being explored. Table 1 summarizes key parameters for the various BEES Flyers constructed over the last four years.

The bioinspired sensor suite consists, of a dragon –fly inspired horizon sensor –"the Ocelli"[16] named after the relevant key organ in the dragon fly responsible for that function, that we have derived inspiration from for this sensor. First results on operational performance of this sensor are described elsewhere[2-6]. Fig 4a shows our latest implementation of the same. The second sensor is the optic flow sensor which is adapted from an existing COTS optic mouse chip utilizing its feature extraction based optic flow sensing capabilities in combination with tailored optics to provide an embedded on –board solution[6-9] on a BEES flyer shown in fig 4b. The third sensor is the insect inspired polarization compass[6-9,17-19] shown in fig 4c.

Flight tests in September 2003 by ANU demonstrated altitude hold and terrain following using the embedded optic flow sensor. Flight tests by ANU in August 2004 featured a new type 1A flyer (shown in figure 5). Smallest of its kind, this 520 g BEES flyer is equipped with the trio of bioinspired sensors including ocelli, polarization compass, and embedded optic flow sensor on board. Engineering innovations utilized to surmount the sun flare problems in the earlier version of the polarization compass tested in 2003 include using long hoods over the diodes. the newest units are stepped so that off-axis light meets a corner reflector prior to getting to the bottom of the hood. Also for the 2004 version of the ocelli, hoods incorporating filters and flare reduction have been prototyped to improve the performance and are vastly improved in terms of connectors, communications protocols, and lower parts count. Further details on this are described in the companion paper by J. Chahl[13] in the same proceedings.

Table: 1

Item	**Type 1** 1.5kg, 01 BEES Flyer (Imaging)	**Type 2** 5 kg, 03 BEES Flyer (Shepherding)	**Type 1A** 1 kg, 02 BEES Flyer Imaging	**Type 1A** 0.5 kg 04 BEES Flyer
Dry Mass	900g	2670g	600g	380gm
Fuel	100g	340g	225g	LiPo battery
Payload	427g	1990g	174g	140gm
Takeoff weight	1427g	5000g	1000g	520g
Engine	178g	698g	145g	51gm
Propeller	9g	58g	8g	6gm

Engine Type	OS 15LA	OS 61FX	OS 10LA	Astro 801V
Propeller Size	20.3cmx15.2cm	28.0cmx20cm	17.8cmx10.1cm	5.5cm x 4cm
Top Speed	≈135km/h	≈165km/h	≈110km/h	≈ 75km/h
Landing Speed	≈45km/h	≈55km/h	≈37km/h	≈ 30km/h
Range	25000m	55000m	37000m	≈12500m
Endurance	>12min	>20min	>20min	>10min
Wing Span	0.81m	1.240m	0.708m	0.708m
MAC	0.396m	0.606m	0.346m	0.346m
Leading edge sweep back	50.8°	50.8°	50.8°	50.8°
Aspect Ratio	2.206	2.206	2.206	2.206
Taper Ratio	0.19	0.19	0.19	0.19
Wing Area	0.297 m^2	0.701m^2	0.227m^2	0.227m^2

Figure 4. (a) Latest version of the dragon-fly inspired ocelli –the horizon sensor. (b) picture of the 5Kg BEES flyer built and tested in 2002-2003, equipped with the optical mouse chip (shown in inset) embedded as an optic flow sensor to accomplish honey –bee inspired altitude hold and terrain following. (c) Latest version of the insect inspired polarization compass.

Figure 5. The Type 1, 520g BEES Flyer version built in 2004 equippewd with the trio of bioinspired navigation suite consisting of the ocelli, polarization compass and the optic flow embedded sensor

IV. Bioinspired Observation/Imagery Mission : BEES-BYU/NASA-JPL Demonstration

This effort is aimed at demonstrating a potential Mars Mission scenario that utilizes algorithms inspired by behaviors observed in birds of prey. The Delta Wing aircraft used for this work are modified versions of the Zagi THL flying wing[20] (shown in figures 6 and 7), and are therefore inexpensive and versatile to allow us to tailor them to our needs. A gimbaled camera system has been developed and integrated onto this airframe to form an "Imaging flyer" which is shown in figure 6 b. All aircrafts are equipped with the Kestrel auto-pilot developed by BYU (shown in figure 6c). The demonstration scenario consists of two unmanned autonomous flyers launched from the home base. The imager is equipped with a camera mounted on a pan and tilt gimbal. The other flyer which represents the lander (or a payload) that needs monitoring/observation as its descends, is equipped with a deployable parachute to simulate a potential "Mars lander" and we call this flyer the "lander flyer", shown in figure 7. The two flyers gain altitude to roughly 500 m and move into a formation where they are separated vertically by 50 m, and separated by a horizontal distance of 75 m. The "lander" flyer deploys its parachute and reaches a constant descent velocity of 4.5 m/s within 20 seconds. After deploy, the autopilot on this "lander flyer" is turned off and it is allowed to free fall. The imaging flyer spirals around the lander, and uses GPS measurements on both flyers to acquire an image of the lander and its parachute in its camera. GPS signals are not used after this point. The imaging flyer spirals downward around the lander, maintaining the image of the lander in its camera field-of-view with a constant vertical separation of 50 m. When the lander touches ground, the imager continues to image the lander for an additional twenty seconds, and then lands autonomously. The actual telemetry data from the test is displayed using a MATLAB movie and an illustration of the same is shown in figure 8. Table 2 shows the key parameters for the two flyers, imaging and "lander" flyer respectively..

Table 2

Item	Imaging flyer	Lander flyer
Dry Mass	800 g	800 g
Fuel	N/A (Electric)	N/A (Electric)
Battery	2 x 1500 mAh Kokam Lithium Polymer	2 x 1500 mAh Kokam Lithium Polymer
Payload	200 g	200 g
Takeoff weight	1000 g	1000 g
Engine	Hacker BL20	Hacker BL20
Propeller	GWS Plastic	GWS Plastic
Engine Type	Electric	Electric
Propeller Size	8X5	8X5
Top Speed	24 m/s	24 m/s
Landing Speed	12 m/s	12 m/s
Range	10 km	10 km
Endurance	30+ min	30+ min
Wing Span	1.21 m	1.21 m
Leading edge sweep back	20 degrees	20 degrees
Aspect Ratio	7.75	7.75
Taper Ratio	.51	.51
Wing Area	0.189 m^2	0.189 m^2

Figure 6. (a) Top view of the Imaging flyer (b) Bottom view of the Imaging flyer showing the camera mounted on a pan& tilt gimbal in a magnified view. (c) Imaging flyer showing the Kestrel auto-pilot embedded within the Imaging flyer and magnified view of the camera in the inset.

Bioinspiration is used to identify the location of the payload in the image. Inspired by the human vision system's ability to segment specific colors under different lighting conditions, a color segmentation algorithm in development, is not affected by illumination variations and is capable of detecting similar colors. The method converts the red, green, and blue (RGB) data into hue, saturation, and intensity (HIS) color space. The intensity component that is sensitive to illumination variations is then discarded. Unlike most other color segmentation techniques that use only hue component for segmentation, both hue and saturation are utilized and two-dimensional thresholds are applied to these two color components. By carefully selecting these thresholds, through the help of a simple calibration procedure, the targeted color and its similar colors can be segmented. This demonstration focused on identification of the colored parachute in the camera image.

Figure 7. The Lander flyer (a) top view of the flyer showing the parachute tucked in at the nose area (b) the lander flyer in flight at El Mirage (c) the lander flyer in free fall towards the lake-bed with its parachute deployed

Figure 8. MATLAB illustration of the flight test data from the demonstration of the Observation Mission Analog using the imaging flyer and the "Lander " flyer

Since birds travel at a much greater speed than their prey, they execute an orbiting motion about their prey during the tracking phase. However, the orbiting motion is not constrained by timed stamped positions along the intended flight path. Therefore traditional trajectory generation techniques are not appropriate. Alternatively, birds maintain a fixed distance to their prey, modifying their flight path for high wind conditions and other environmental disturbances. Distilling these principles, a navigation algorithm is developed that is based on the distance to the desired orbit, adjusting the flight path to accommodate high wind conditions and other environmental disturbances. Simulation results for high wind conditions demonstrate motion that is qualitatively similar to the motion of birds in heavy winds. The image-directed control algorithm, the Vulture algorithm, inspired by the behavior displayed by birds of prey as they hunt[21] and its modified form, the buzzard algorithm is specifically designed for circular flight paths. The vulture algorithm was developed to allow tracking of more complicated flight paths and is described in more detail in another paper[22]. The demonstrations in September 2004, showcased the buzzard algorithm and the color segmentation algorithm for the first time.

V. Future BEES Research Areas

Figure 9 shows some of the selected technologies representing a small subset of the many possible bioinspired technologies. Within the "BEES for Mars" Project, we have begun to demonstrate the impact of some of these sub areas. The areas shown in this figure actually can be neatly woven in to represent the development of a Mission enabled by these constituent technology developments in a systematic progression from fig. 9(a) to 9 (g). For example the BEES for Mars project has currently focused on a bioinspired sensor suite as shown in 9 (a), embedded in a traditional airframe hardware 9(b) incorporating bioinspired control paving the way for autonomous navigation by BEES flyers through difficult terrain 9(c). Combining this, with the developments accomplished within this project in the area of bird prey behavior inspired and neural network inspired possibilities for visual search, tracking and processing 9(d), we have obtained a solid foundation for a BEES enabled system offering new capabilities that are leap ahead of the existing. Further strides are possible by using bioinspired ideas for antenna design emerging from genetic algorithms[22] and evolutionary research[22]. A new resource 9(e) exists for compact antenna design and direction finding utilizing[22] the ideas distilled from the fruit fly ORMIA emerging from its hyper acute directional hearing sensitivity. The autopilot and imaging camera are examples of instruments that are already demonstrated within this project. Finally packaging and deployment strategies 9 (f) is another rich resource area where biology can help and putting it all together in a mission architecture 9 (g) , the multitude of co-operative behaviors[22] observed in nature can serve as a good guide to providing solutions and accomplishing our goals of exploring the hardier and new locales both on Earth and Mars or beyond.

Figure 9. Illustration exhibiting a small subset of the many possible bioinspired technologies that are being demonstrated or studied within the "BEES for Mars" project with systematic progression from 9(a) to 9 (g) enabling the BEES Missions.

VI. BEES Mission Applications

BEES flyers have the potential to enable a large variety of new capabilities. The following is a partial list of the same.

- Provide high-resolution images of the Mars surface.
- Explore canyons and other regions on Mars that are not accessible to rovers.
- Track dust storms in real-time.
- Enhance map resolution thus increasing path planning capabilities for rovers.
- Provide ad hoc communication relays between landers on the Mars surface.
- Image the descent and landing of mission payloads sent to Mars - Black box functionality
- Distribution of Instruments over a wide area and over rugged terrain

Some specific scenarios are illustrated in figures 10 through 12. The common factor in all these is utilizing a small airframe that can be surface launched from a lander in an example Mars Mission. Such surface launched flyers can be used for Observation of significant ephemeral phenomenon such as descent and landing of landed payloads (10) or dust storms (11). The launch of the flyer or flyers from the lander can be timed in synchrony with the event that needs to be observed and the flyers in flight can collect valuable imagery and other data by also providing a good means to distribute a large variety of microinstruments. This capability can particularly be tailored as a risk mitigation tool for observing landed missions. Further in figure 12, are illustrated, a near term and far term scenario for long range exploration of Mars and potentially hard to reach constrained areas such as craters and canyons. Single imaging flyers by themselves can revolutionize the way we explore by covering tens of kilometers in a few minutes as shown in 12 (a) . They are ideal for mapping out paths for rovers. The surface launched flyers both of the imaging and shepherding kind can in combination provide exploration over really large, hundreds of kilometers of expanses of area in a short time of tens of minutes. Shepherding flyers can form suitable aerial telecom ad-hoc hubs between landers to cover even more ground as shown in both 12 (a and b), (b) being a more complex scenario with multiple landers, rovers and flyers.

Figure 10. Illustration of surface launched Imaging flyers, launched from a "BEES lander" to observed the descent and landing of an newly entering lander Mission and its payload.

Figure 11. Illustration of surface launched Imaging flyers, launched from a "BEES lander" to observe a dust storm on Mars

Figure 12. Illustration of surface launched Imaging flyers, launched from a "BEES lander" to perform long range exploration of the Mars sites of interest, (a) covering ~ tens of Kilometers in a few minutes and (b) covering hundreds of kilometers in tens of minutes using multiple landers and shepherding flyers as aerial telecommunication hubs.

VII. Conclusion

The progress made in development of bioinspired sensors so far has led to a series of successful flight tests demonstrating altitude hold and terrain following. In the area of bioinspired search track algorithms, particularly the following highlights are accomplished:

- Demonstrated successfully operation of gimbaled camera for aerial imaging by Imaging flyer autonomously, with launching and landing being performed in the RC control mode. Autonomous aerial imaging from up to 4Km distance from the launch base was accomplished successfully.
- Demonstrated the buzzard algorithm for first time to track a descending payload at a fixed safe altitude away from the payload executing a flight orbit within a safe diameter around the payload
- Demonstrated for the first time the color segmentation algorithm and its ability to acquire imagery data from objects on ground and track the object while the Imaging flyer is in autonomous flight. Initial acquisition is done using the GPS co-ordinate of the object

The integration of the bioinspired sensors and the bioinspired algorithms for search and tracking in future years will realize the full impact of the concept of BEES, weaving it further with bioinspired innovations in communications, conformal embedded antenna design and instrumentation, leading to co-operative Mission architectures blending the best of the conventional with bioinspired innovations providing a leap in the functional capability, as we have already begun to realize through these early demonstration flight tests within our "BEES for Mars" project.

Acknowledgments

The research described in this publication was carried out at the Jet Propulsion Laboratory, California Institute of Technology, the Brigham Young University and the Australian National University under a contract with the National Aeronautics and Space Administration (NASA) and was sponsored by the NASA Intelligent Systems Program. We would like to acknowledge the dedicated effort of Dr. Javaan Chahl (the bioinspired navigation team lead), Dean Soccol, Geno Ewyk, Jim Neale and Saul Thurrowgood at Australian National University in providing support to the development and testing of the BEES Navigation suite and flyers described in Section III. We would like to acknowledge the dedicated effort of Prof. Randy Beard (the bioinspired search and track, team lead), Prof. D.J. Lee , Morgan Quigley, David Hubbard, Steve Griffiths, Blake Barber, Andrew Eldridge, Derek Nelson at Brigham Young University in providing support to the development and testing of the BEES Observation and Imaging Mission demo and flyers described in Section IV. We would like to acknowledge all members of our project team.

References

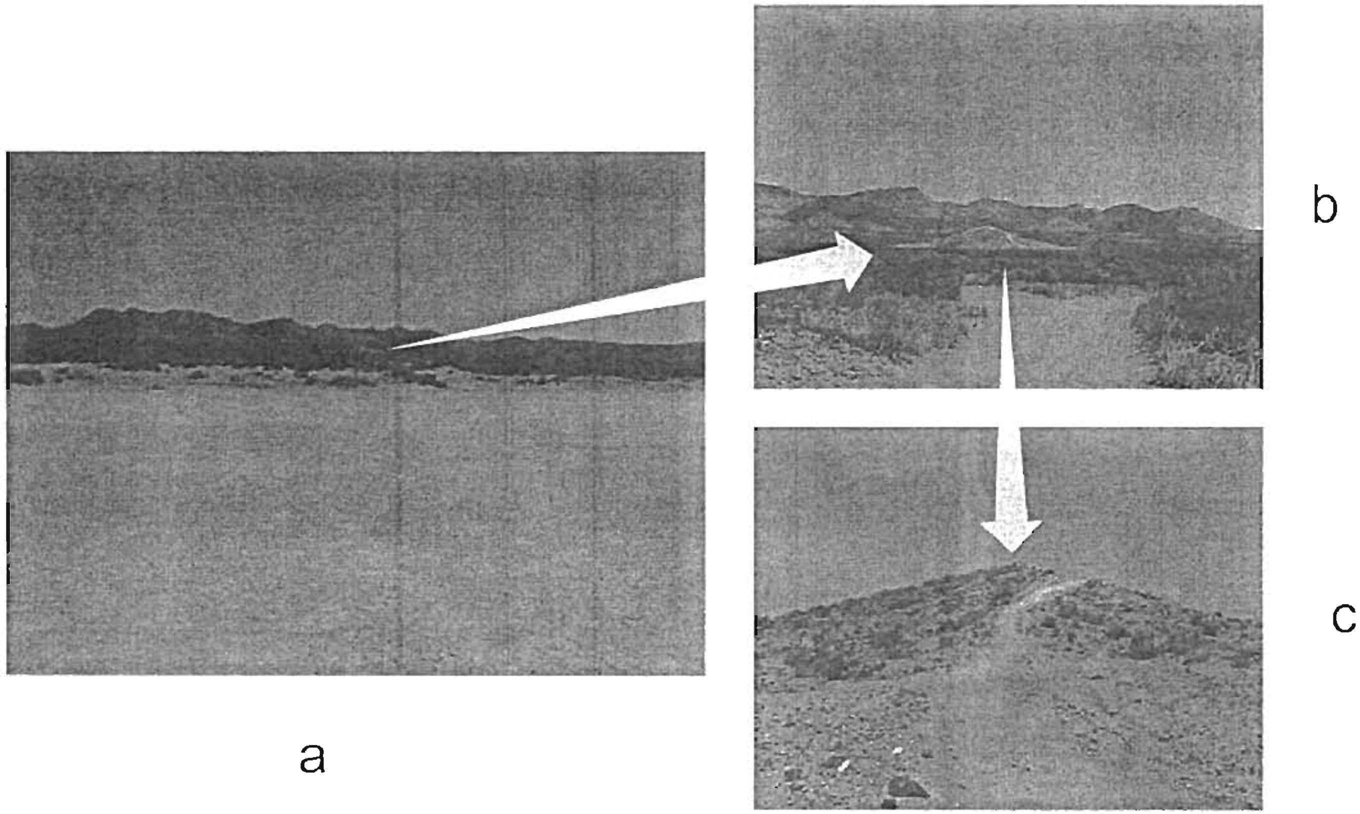


fig1

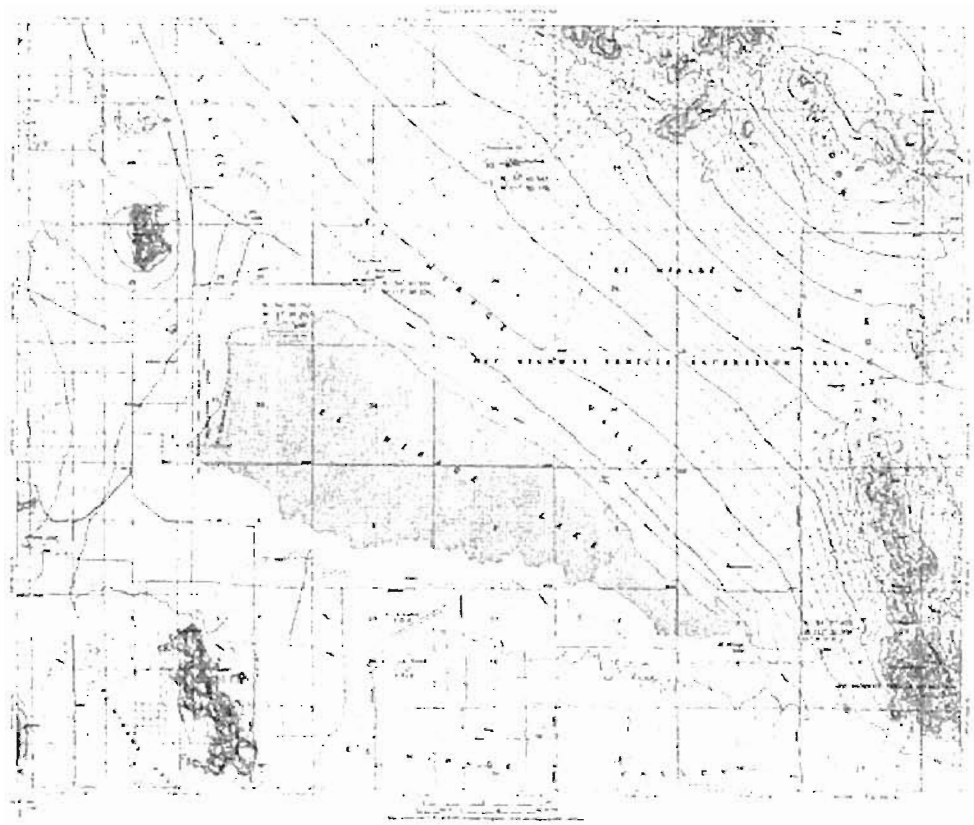


Fig 2

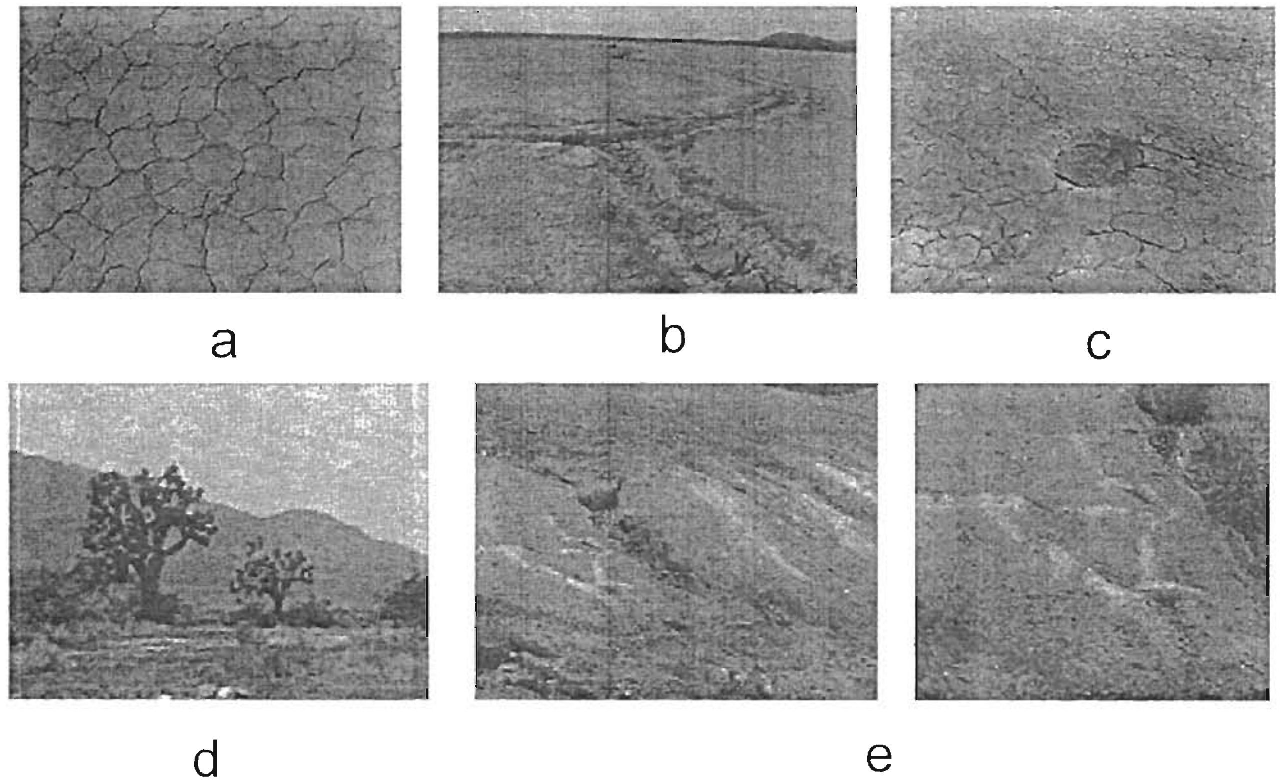
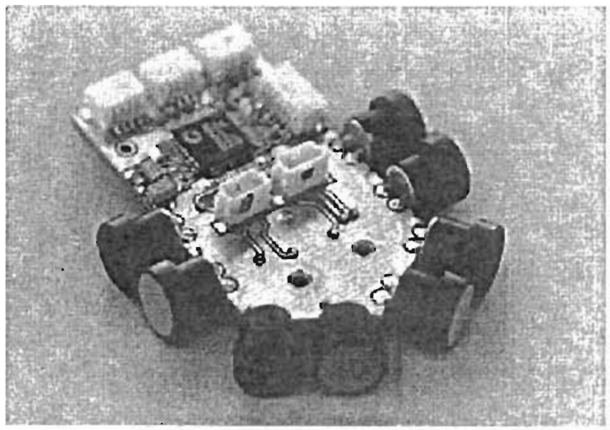
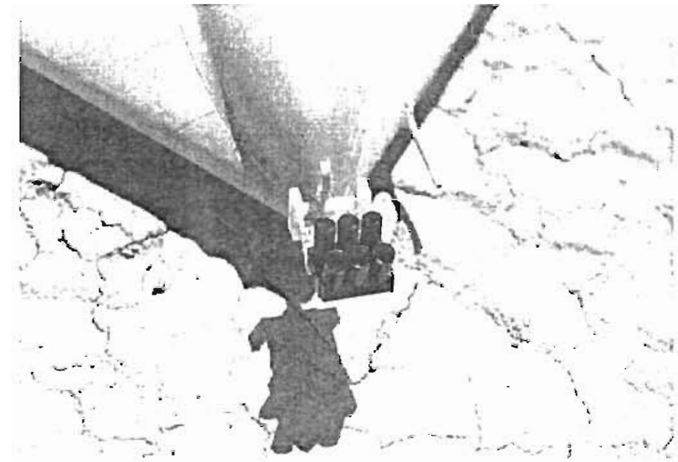


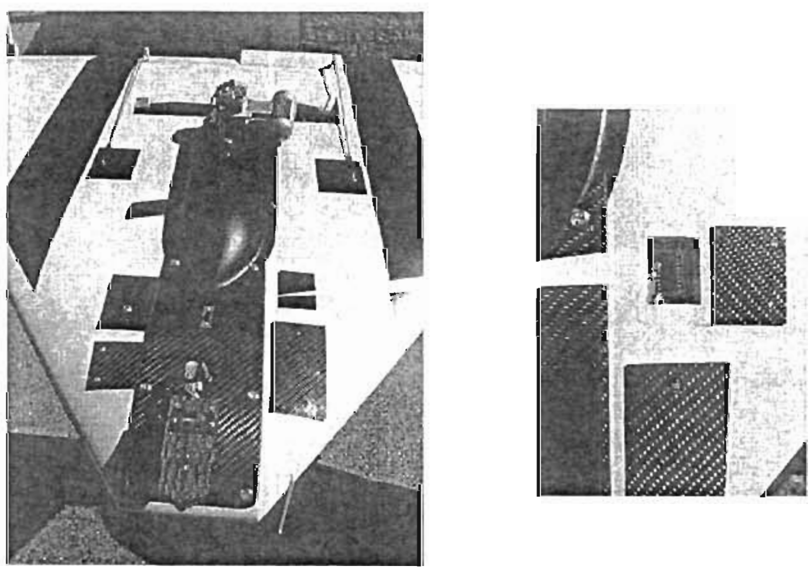
Fig 3



a



c



b

Fig 4

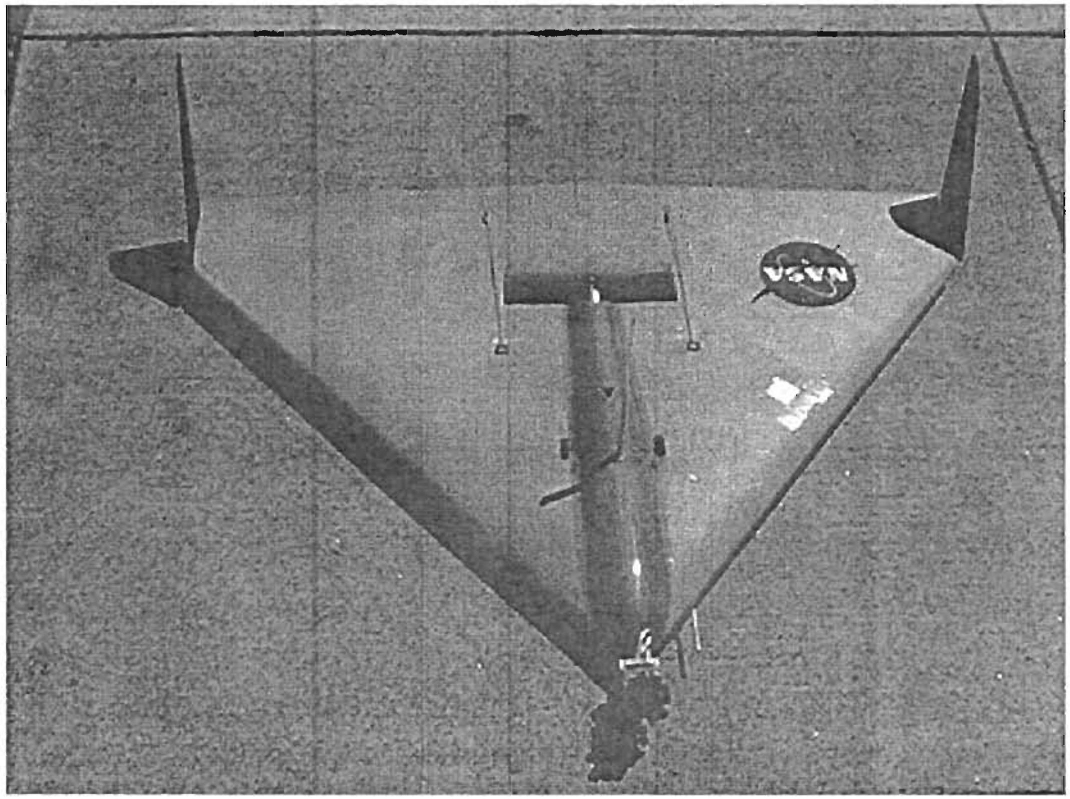


Fig 5

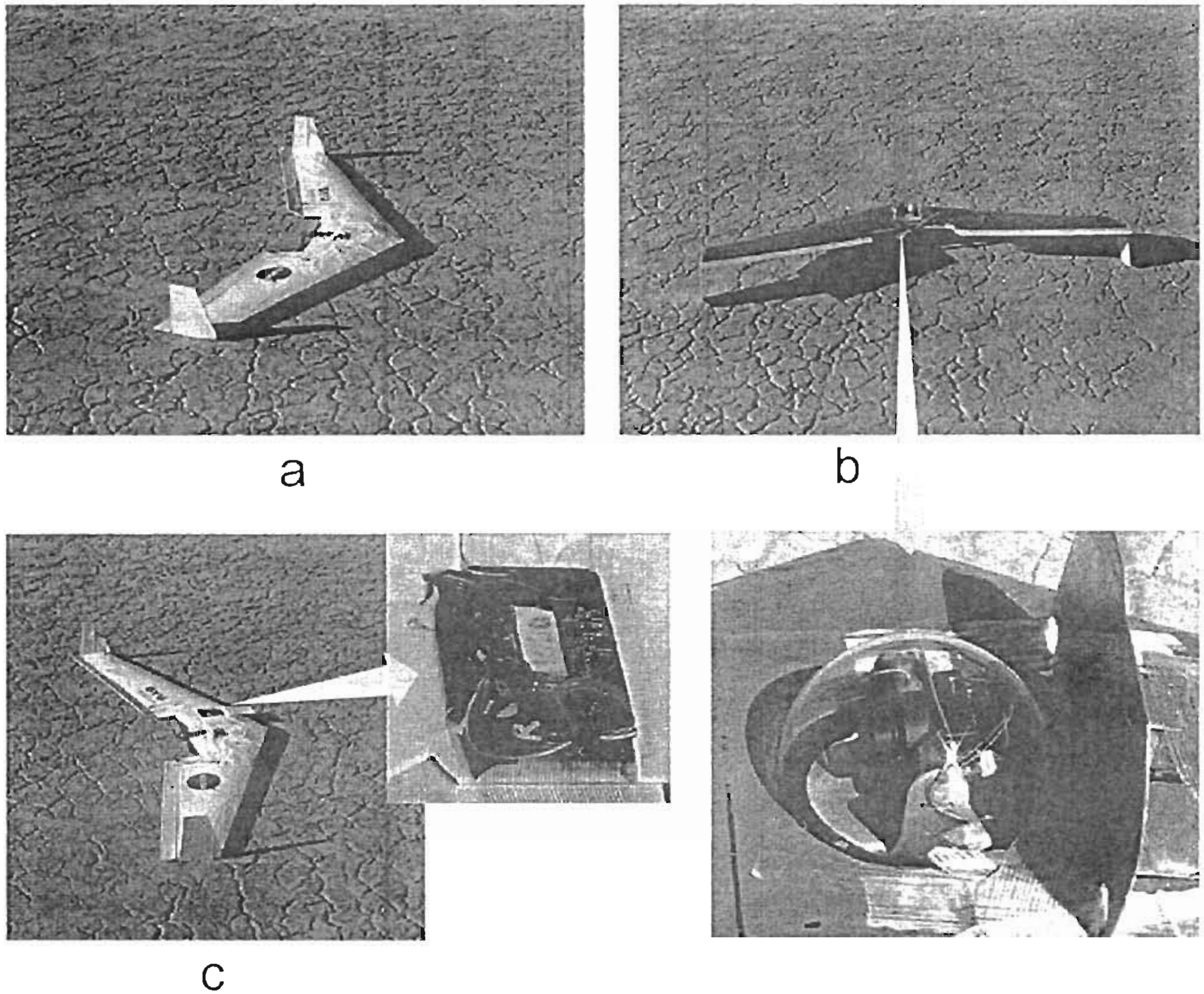
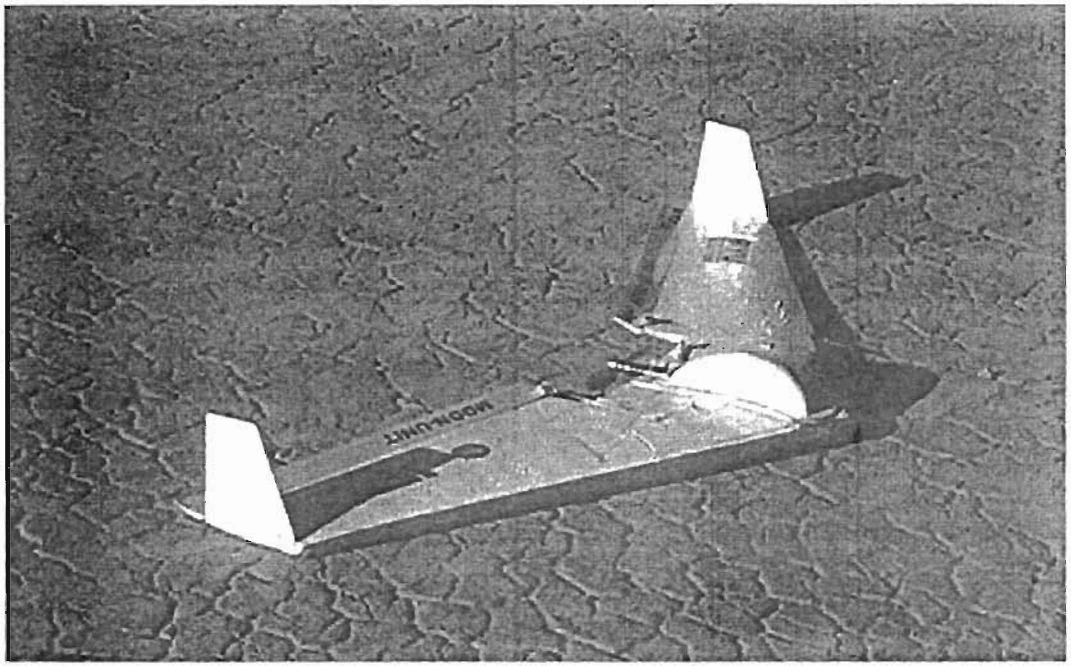
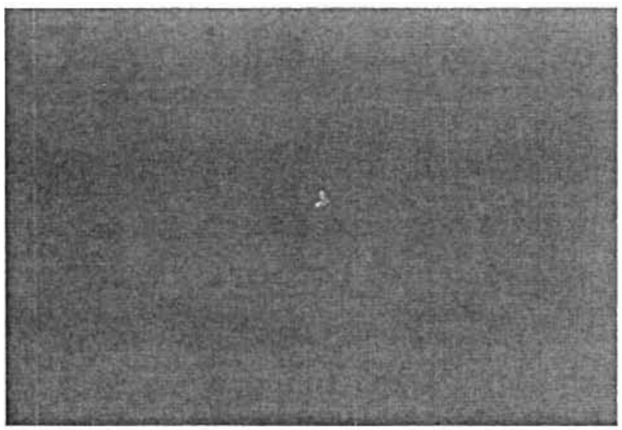


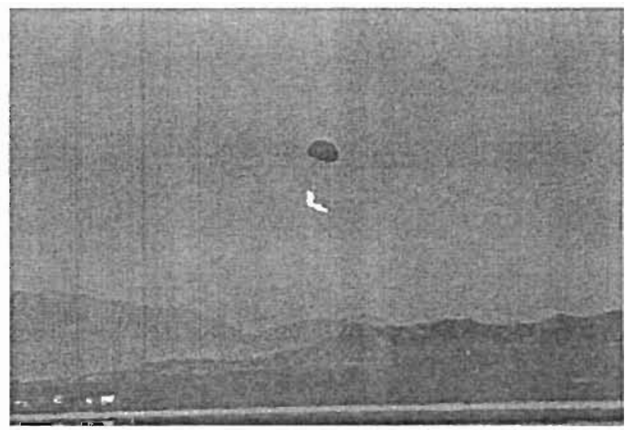
Fig 6



a

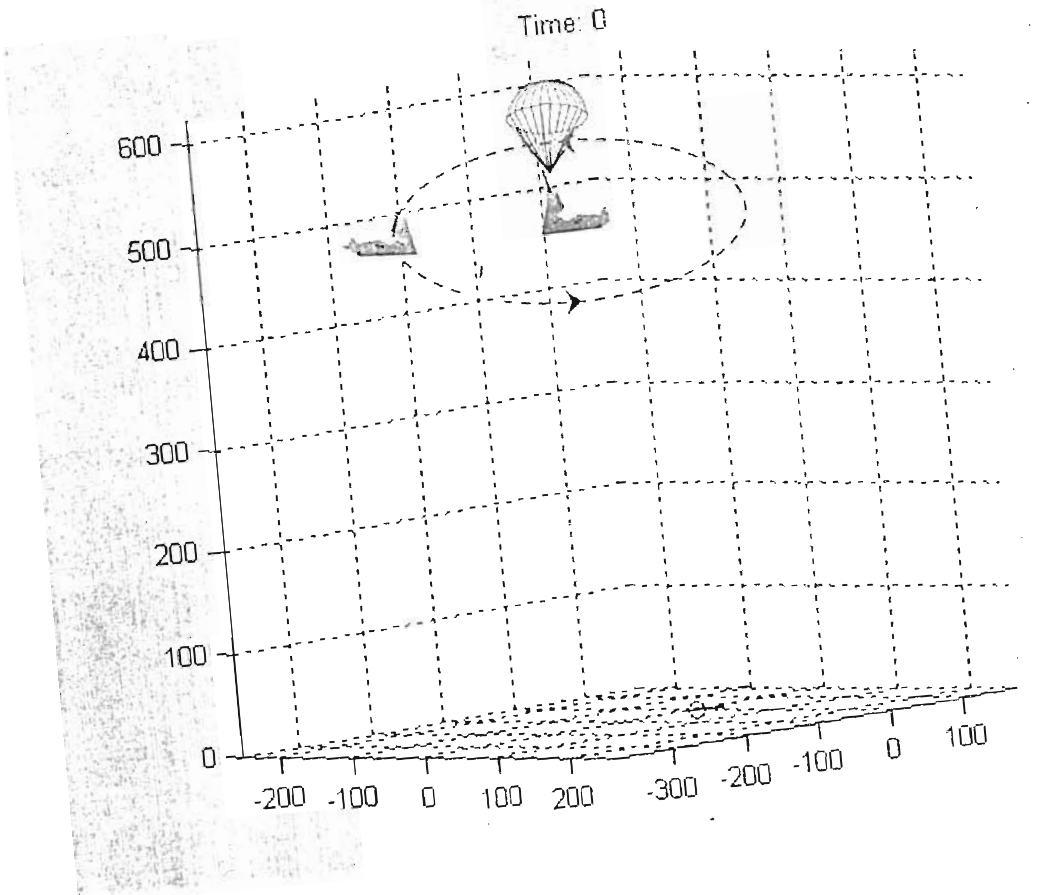


b



c

Fig 7



Time: 0
600
500
400
300
200
100
0
-200
-100
0
100
200
-300
-200
-100
0
100

Fig 8

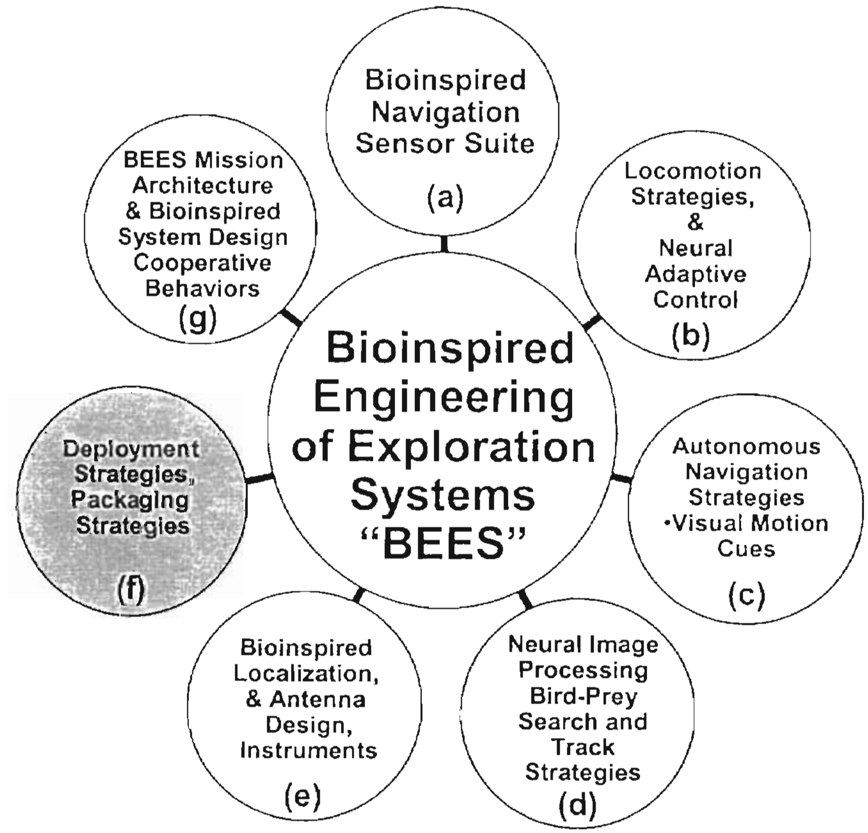

Bioinspired Navigation Sensor Suite
(a)
Locomotion Strategies, & Neural Adaptive Control
(b)
Autonomous Navigation Strategies •Visual Motion Cues
(c)
Neural Image Processing Bird-Prey Search and Track Strategies
(d)
Bioinspired Localization, & Antenna Design, Instruments
(e)
Deployment Strategies, Packaging Strategies
(f)
BEES Mission Architecture & Bioinspired System Design Cooperative Behaviors
(g)
Bioinspired Engineering of Exploration Systems "BEES"

Fig 9

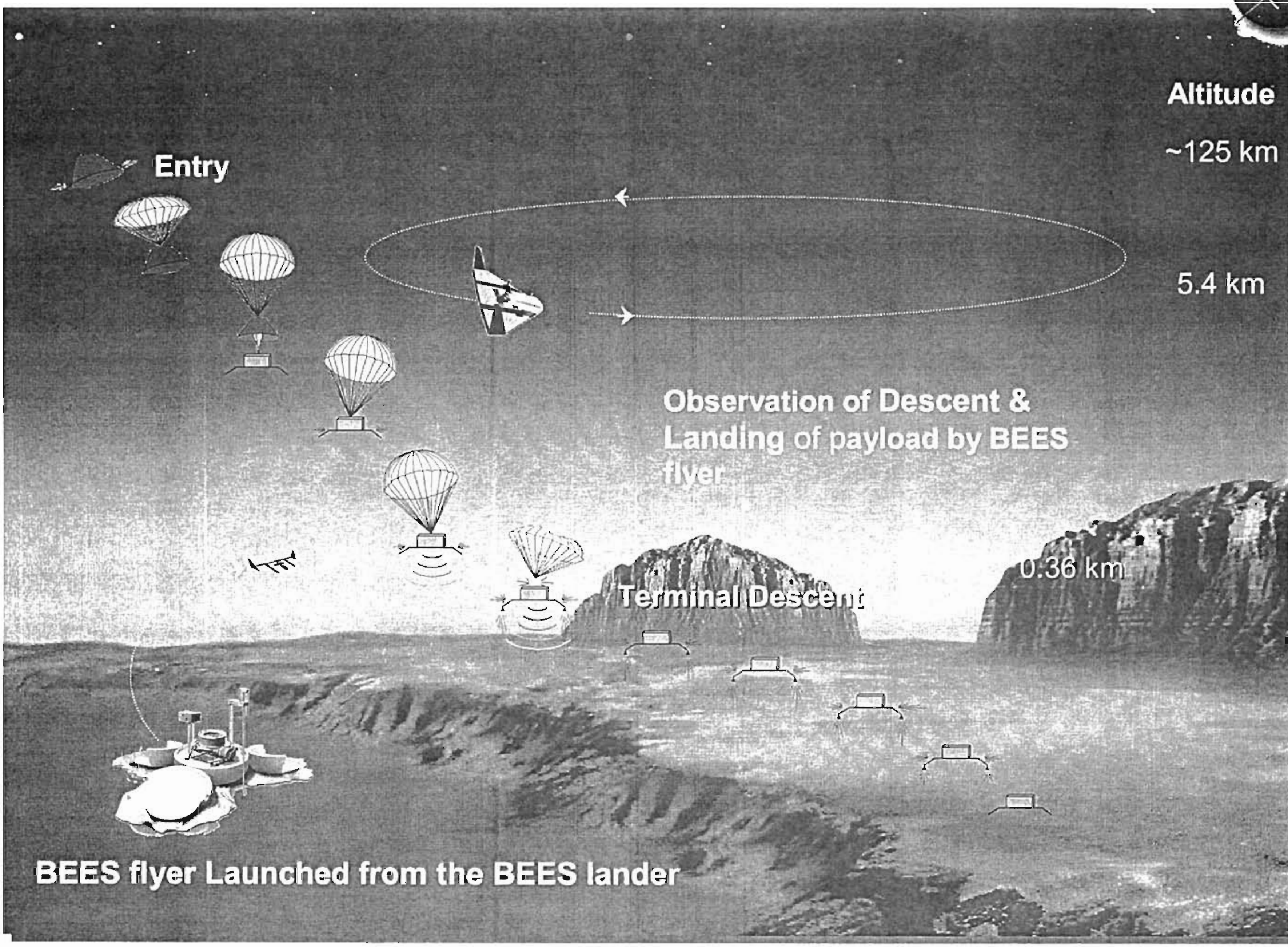

Altitude
~125 km
Entry
5.4 km
Observation of Descent & Landing of payload by BEES flyer
0.36 km
Terminal Descent
BEES flyer Launched from the BEES lander

Fig 10

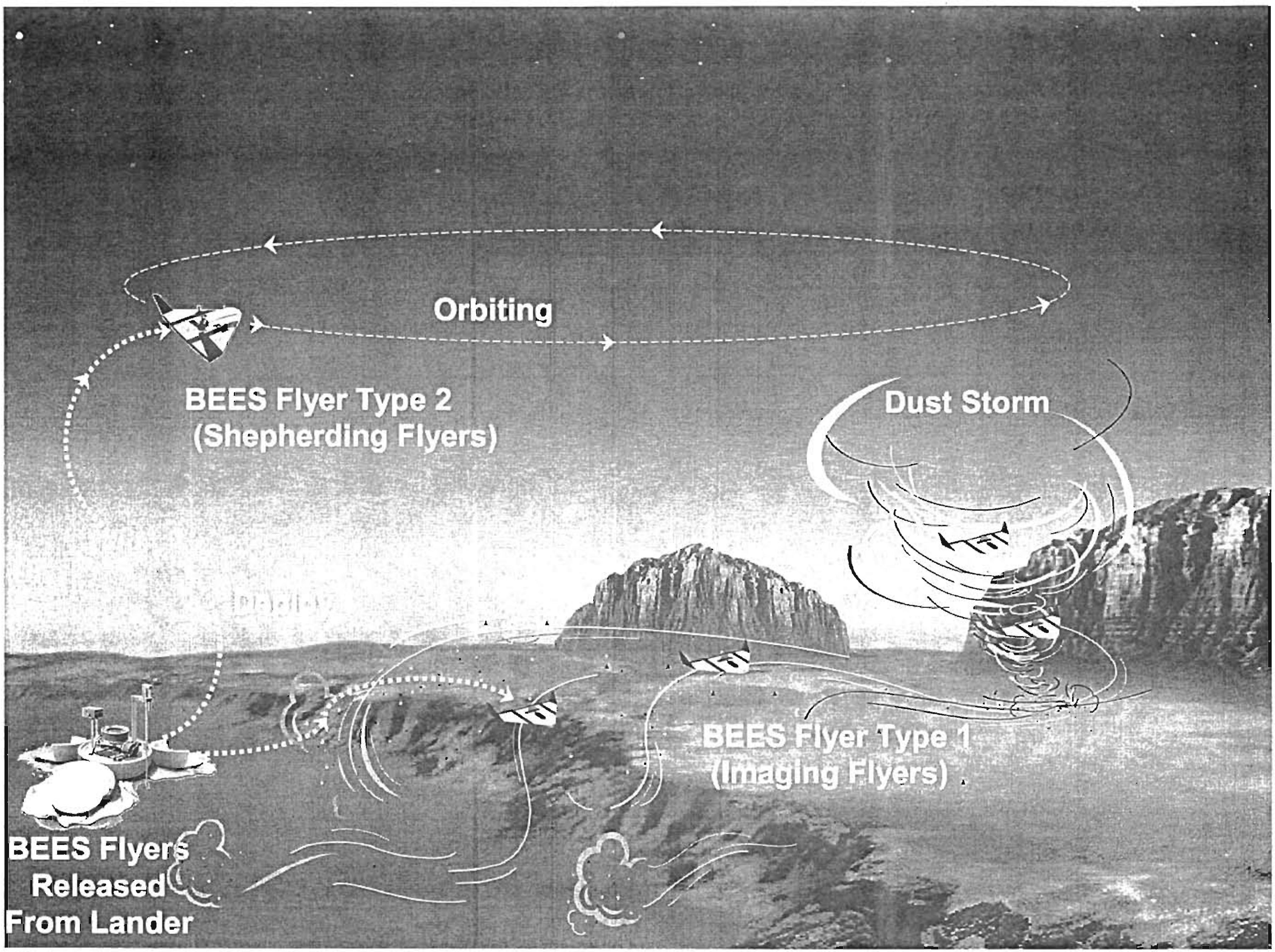
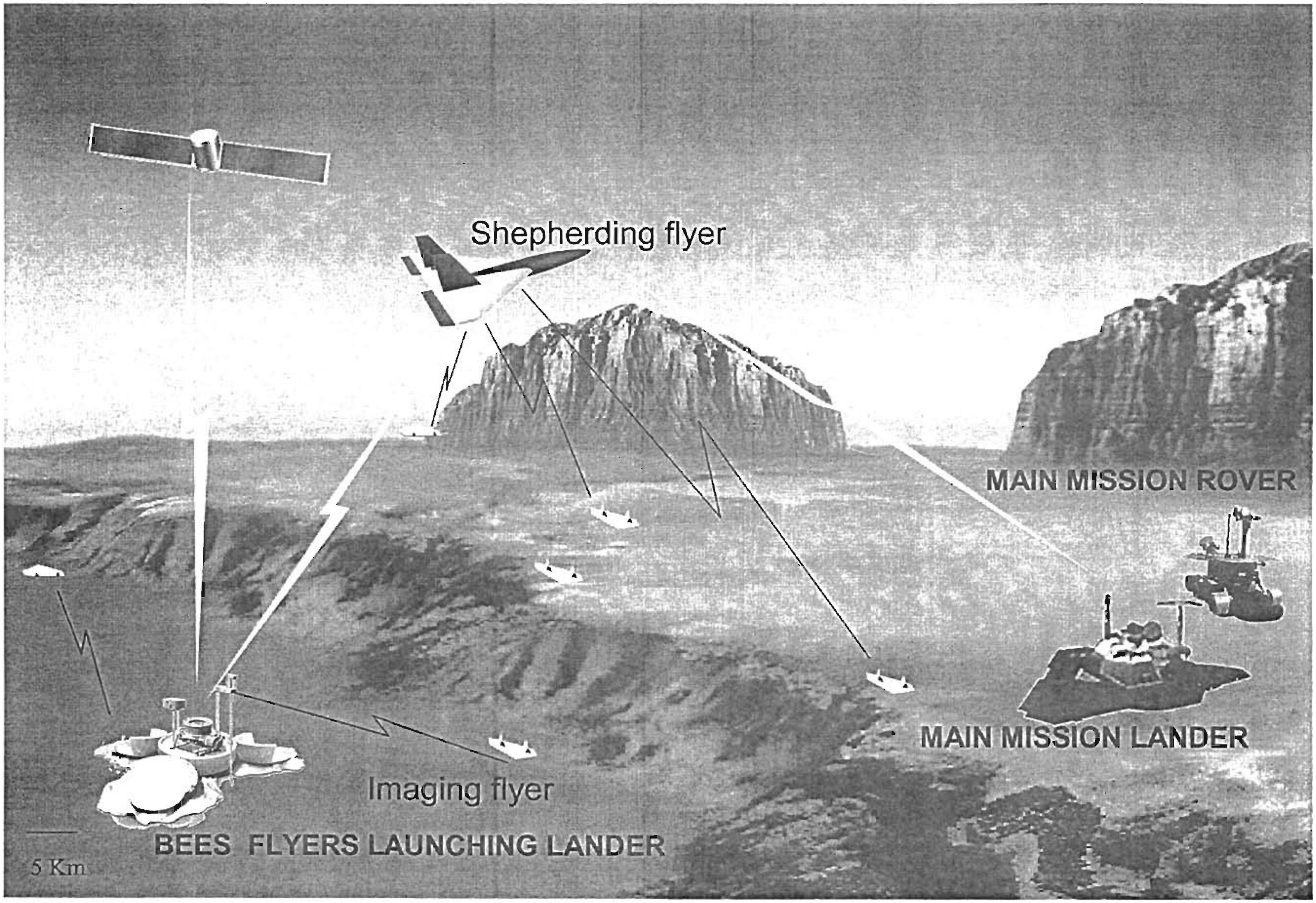
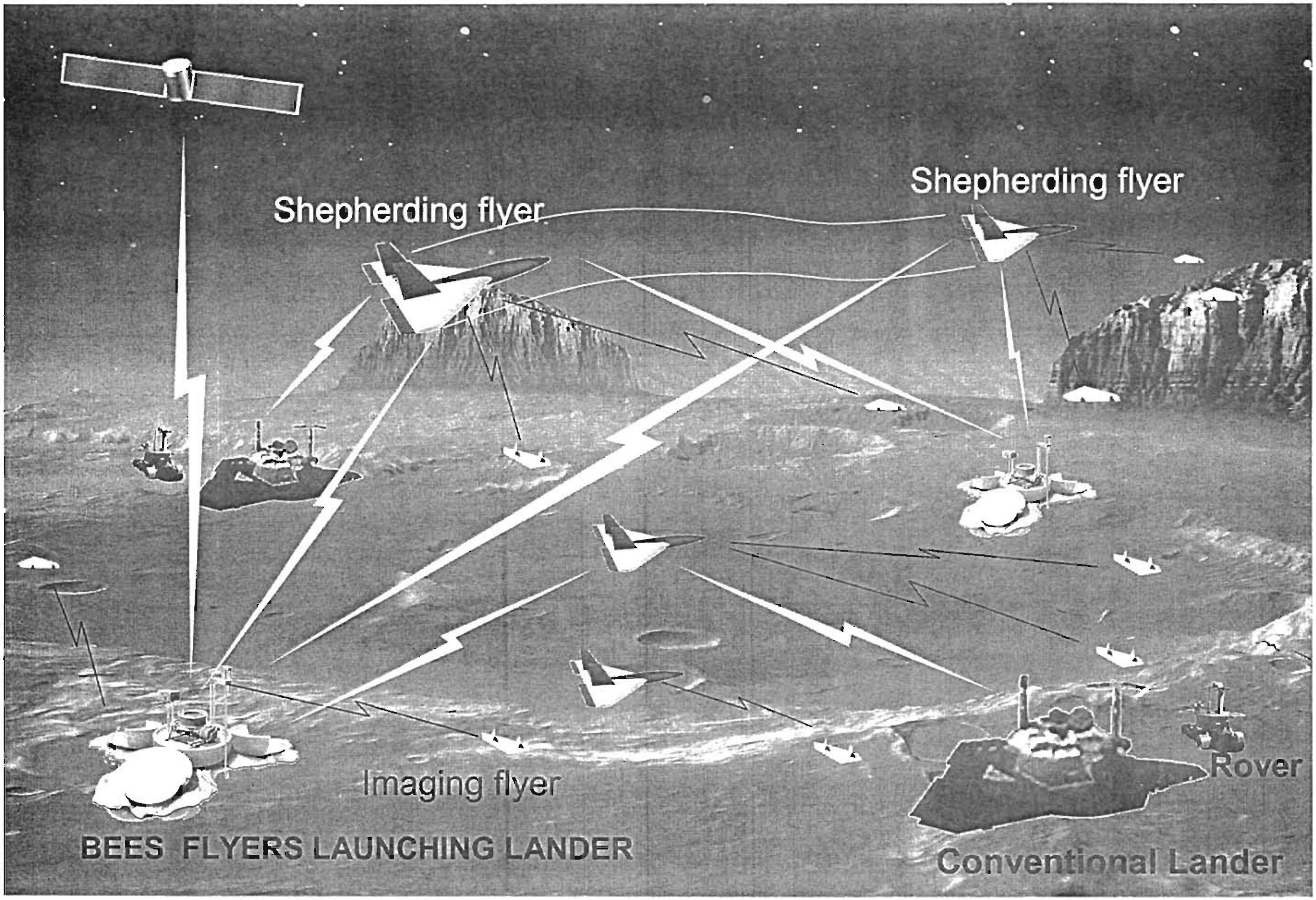

Orbiting
BEES Flyer Type 2
(Shepherding Flyers)
Dust Storm
BEES Flyer Type 1
(Imaging Flyers)
BEES Flyers
Released
From Lander

Fig 11


Shepherding flyer
MAIN MISSION ROVER
MAIN MISSION LANDER
Imaging flyer
BEES FLYERS LAUNCHING LANDER
5 Km

a

Fig 12


Shepherding flyer
Shepherding flyer
Imaging flyer
Rover
BEES FLYERS LAUNCHING LANDER
Conventional Lander

b

Fig 12