Artificial Neural Membrane Flapping Wing

NIAC Phase I

Pamela A. Menges, Ph.D.
Principal Investigator
Aerospace Research Systems, Inc.

NIAC Fellows Meeting
March 7 - 8, 2006
Atlanta, Georgia

Acknowledgements

Artificial Neural Membrane Flapping Wing
Phase I Study

Funded by the
NASA Institute for Advanced Concepts
An institute of the
Universities Space Research Association.

NIAC
NASA Institute for Advanced Concepts

Project Support

Subcontractors & Consultants

Leap Smart, Inc. & Christian Moore (Chief Media Designer, Simulation & Animation Design Services)

Dr. C. E. Grey, Ph.D. (Project Metallurgist & Chemist)

Aerospace Research Systems, Inc. (ARSI) engineering staff: John Cell, Dave Stuart, Bob Rossman and Brenda Hogan.

ARSI
Aerospace Research Systems, Inc.

Special Thanks

Mr. Mel Duran (President, Jemez Technology, Inc & Retired Los Alamos Nat'l Lab Space Engineering LANL/NIS-4 Group Leader)

Dr. Richard Averitt, LANL/Center for Integrated Nanotechnology

Los Alamos National Laboratory Technology Transfer Office

Artificial Neural Membrane Flapping Wing: Introduction

Highly complex, non-linear concept.

Integrates (seemingly) unrelated technologies.

Requires new methods in mathematical biology and new applications in applied general topology.

Is highly dependent on emerging technologies.

ARSI
Aerospace Research Systems, Inc.

Artificial Neural Membrane Flapping Wing: Introduction

Proposed to investigate the development of an artificial neural membrane (ANM) flapping wing as a demonstration of the potential of neural engineering and advanced materials to create a revolutionary technology based in biomimetics and nanoscience.

ARSI
Aerospace Research Systems, Inc.

Artificial Neural Membrane Flapping Wing: Introduction

Artificial Neural Membrane Flapping Wing (?)

New class of intelligent functional structures

Experience in functional structures

Current resident experience and technology

Identification of primary thrust areas for development

Materials & Structures, Computational & Simulation, Aerodynamics

Identification resources supporting thrust areas

Establish current and emerging science including resources to for further study

Artificial Neural Membrane (ANM) Technology

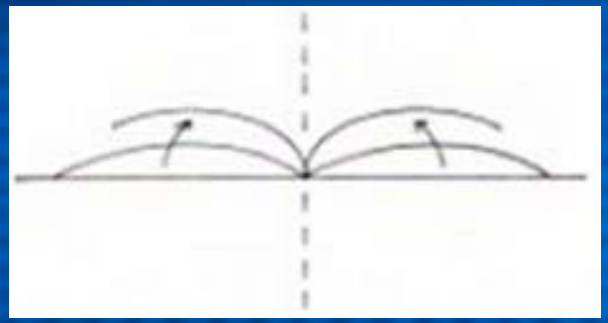
Applications and potential

ARSI
Aerospace Research Systems, Inc.

Artificial Neural Membrane Flapping Wing: Introduction

Proposal conceptualized configuration of carbon nanotubules embedded in the outer polymer capsule of a membrane matrix.

Integration concept based on ARSI's force measurement and A-neuron sensors (concept right).



Simple bi-model or quasi-steady state flapping wing.

Initial concept of a thin film layered matrix with embedded nems.

Artificial Neural Membrane Flapping Wing: Introduction

Advances in materials and computational methods have provided a new environment for the development of artificial neurons as device resident controllers for structures and vehicles.

ARSI
Aerospace Research Systems, Inc.

Artificial Neural Membrane Flapping Wing: Introduction

The ARSI Systems Engineering Laboratory with developed A-neuron sensors for optronic and detector systems.

A-Neuron Sensor w/λ detection

ARSI
Aerospace Research Systems, Inc.

Artificial Neural Membrane Flapping Wing: Introduction

Proposal was based on the success artificial neuron or A-neuron sensor concept developed by ARSI to provide a stable, thin film detector for IRST and coherent light hazards.

ARSI
Aerospace Research Systems, Inc.

Neural Networks: Neurogenesis Algorithms

In the 1980's developed the Neurogenesis Algorithms from the study of the differentiation of chick embryos and the development of the CNS and PNS of vertebrates.

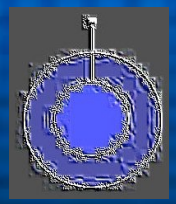
Neurogenesis models were developed from observational data of developmental anatomical changes of embryos as well as signal analysis of neurons in vivo and in vitro.

ARSI
Aerospace Research Systems, Inc.

Experience in Multifunctional Smart Structures

Extensive experience in engineering thin film, optical and composite sensors. Including:

- High-temperature
- Variable frequency
- Embedded sensors
- Radiation detectors
- Board level process monitoring



ARSI μ-G Sensor
0.2 mm

ARSI Physiological Sensor

ARSI
Aerospace Research Systems, Inc.

Artificial Neural Membrane Flapping Wing:Concept

Named Sophia meaning “knowledge” and incorporating the ARSI Neurogenesis Module that integrates self-generating neural networks.

Based on topological algorithms that allow for the simulation of a network on a network.

Current Phase I study investigated network morphing and simulation using topological and algebraic mapping methods.

ARSI
Aerospace Research Systems, Inc.

Artificial Neural Membrane Flapping Wing:Concept

Applications

Near Term Applications (5-10 years)

- Global Environmental Monitoring System
- ARSI Sophia GEMS Concept

Future Applications (10-20 years)

- ARSI Martian MAV Planetary Remote Sensing & Communication Systems
- Orbital ANM Ion Propelled Vehicle

ARSI
Aerospace Research Systems, Inc.

Artificial Neural Membrane Flapping Wing:Concept

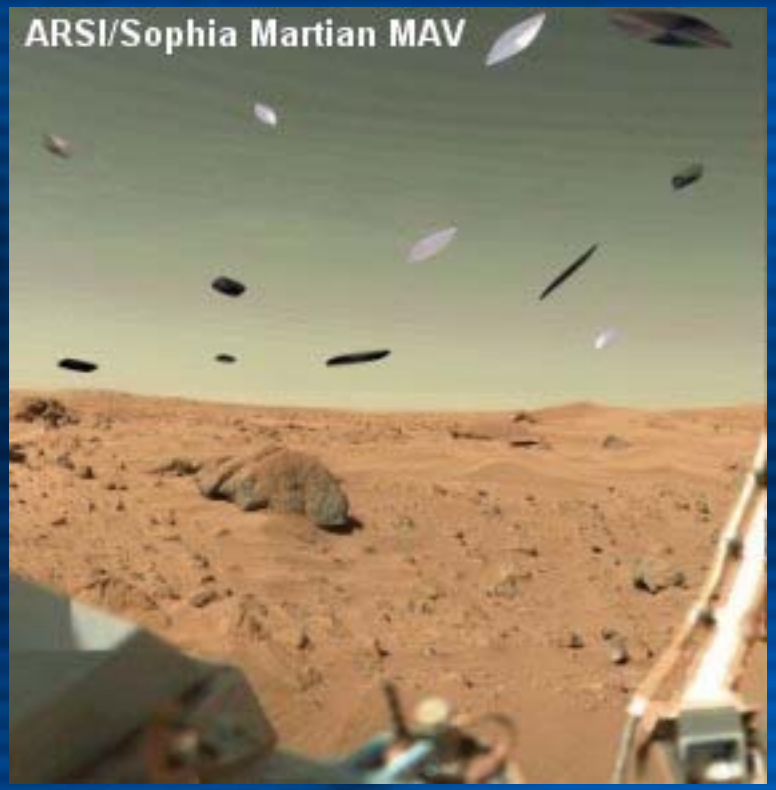


Image: NASA/ARSI/Leap Smart, Inc.

The artificial neural membrane or ANM flapping wing is seen as a multifunctional communications and remote sensing platform for planetary exploration.

ARSI
Aerospace Research Systems, Inc.

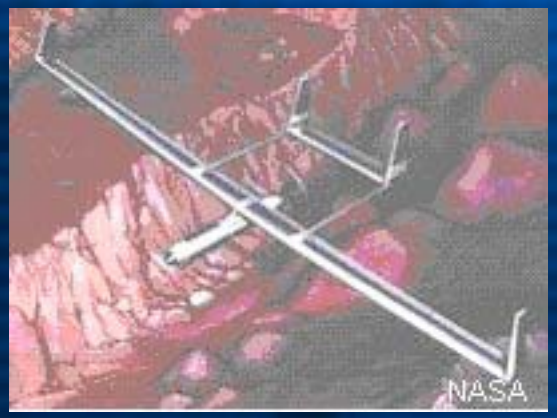
Artificial Neural Membrane Flapping Wing:Concept

Robust multifunctional platforms covering hundreds or thousand of square kilometers providing a Delay Tolerant Network (DTN) for planetary studies and support for communications, weather, radiation monitoring for future astronauts.

ARSI
Aerospace Research Systems, Inc.

Artificial Neural Membrane Flapping Wing:Concept

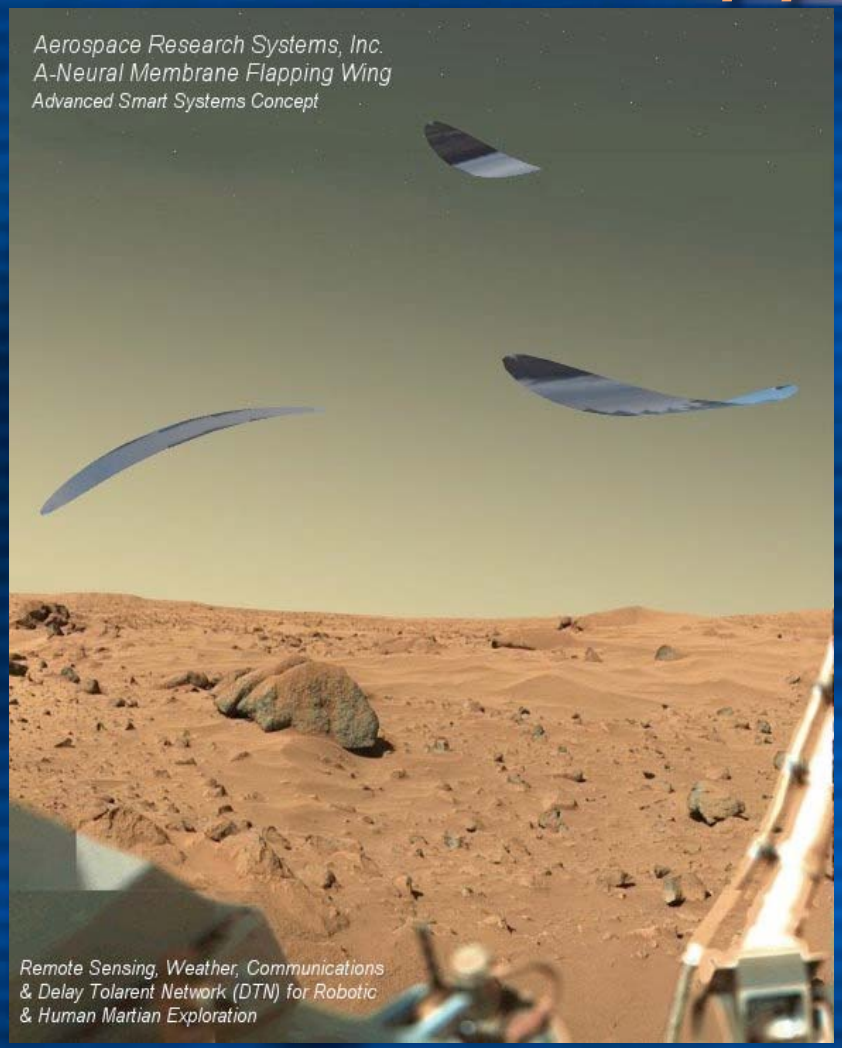
Martian Aircraft



1970's design was generated by NASA Dryden based on a hydrazine-fueled version of the Mini-Sniffer aircraft.

In the early 1990's, a solar aircraft concept was generated by NASA Glenn.

Artificial Neural Membrane Flapping Wing:Concept



Future Martian Microaerial Vehicles (MAV) will need to be fault tolerant, provide robust communications & remote sensing information and cover large areas.

Artificial Neural Membrane Flapping Wing:Concept

Advantages of airborne platforms for planetary studies:

- Airborne platforms can achieve science objectives difficult to complete from orbit or from surface rovers.

- They can cover much larger distances in a single mission and are not limited by the terrain.

- Improved imaging and sensor missions using airborne platforms.

- Produce images of more than a magnitude higher resolution than state-of-the-art orbiting spacecraft.

ARSI
Aerospace Research Systems, Inc.

Artificial Neural Membrane Flapping Wing:Concept

Adaptive A-Neural Systems provide an advanced learning platforms for investigating unknown environments.

ARSI
Aerospace Research Systems, Inc.

Artificial Neural Membrane Flapping Wing: Concept

Martian weather and atmospheric sampling.

Radiation survey of Mars.

Near IR spectrometry, essential to analyzing mineral deposits.

High spatial resolution magnetometry, that may provides answers to the origin of high crustal magnetism seen from orbit.

ARSI
Aerospace Research Systems, Inc.

ANM Flapping Wing: Thrust Areas

Thrust areas are specifically directed at developing complex functional nanostructures, a new class of intelligent structure.

- Materials & Structures
- Computational & Simulation
- Aerodynamics

ARSI
Aerospace Research Systems, Inc.

ANM Flapping Wing: Thrust Areas

Materials & Structures

Mechanics, force distribution, interaction of nanoscale structures, integration of nems

Computational Aspects

Governing equation for a quasi-steady state flapping wing, neural algorithms, topological networks, control systems

Aerodynamics

Airfoil, stability, flow distribution, performance in earth and Martian atmospheres

Wing Geometry & Aerodynamics: Computational & Physical Aspects

Chose a flapping wing insect model to provide a consistent proven computational model with physical data for ANM Flapping Wing Study

In order to determine the potential for an ARSI Neural Controller to recognize flapping wing flight with a given geometry.

ARSI
Aerospace Research Systems, Inc.

Wing Geometry & Aerodynamics: Computational & Physical Aspects

Quasi-Steady State Flapping Wing Model

Chose because of consistently valid research supporting the model.

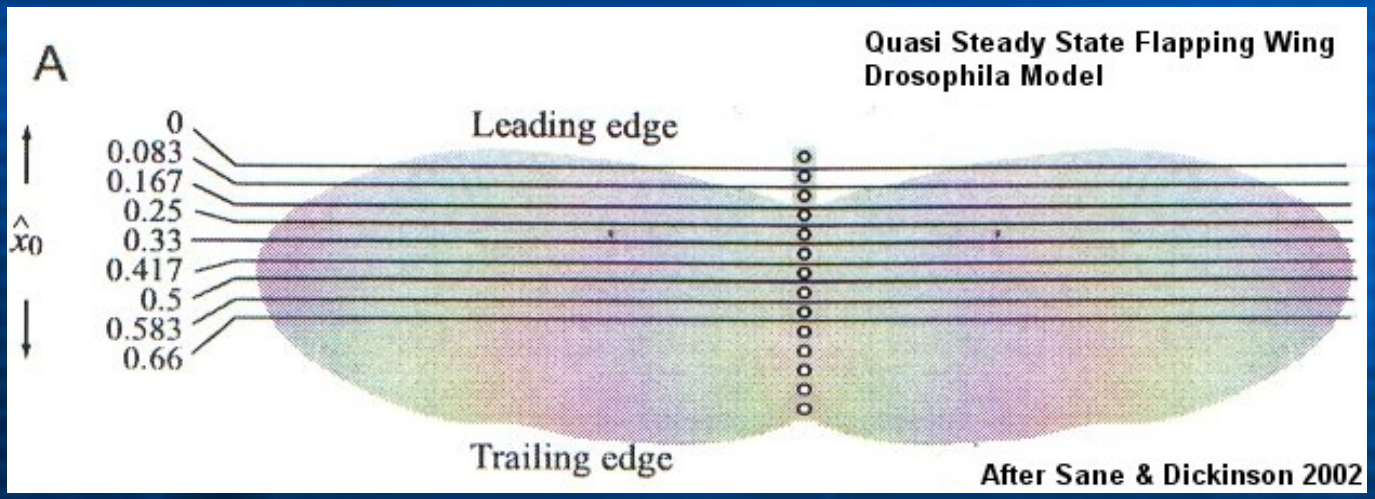
Based on physical models fabricated and tested by Sanjay Sane and Michael Dickinson, University of California-Berkeley.

Provided rigorous and well defined computational models.

Sane, S. P. & Dickinson, M.H. (2002). The aerodynamic effects of wing rotation and a revised quasi-steady state model of flapping flight. *J. Exp. Biol.* 205: 1087-1096.

ARSI
Aerospace Research Systems, Inc.

Wing Geometry & Aerodynamics: Computational & Physical Aspects



This wing geometry lends itself to higher stability for a membrane based vehicles.

Wing Geometry & Aerodynamics: Computational & Physical Aspects

$$F_a = \rho \frac{\pi}{4} R^2 \bar{c}^2 (\ddot{\phi}\sin\alpha + \dot{\phi}\dot{\alpha}\cos\alpha) \int_0^1 \hat{r}\hat{c}^2(\hat{r})\mathrm{d}\hat{r} - \ddot{\alpha}\rho \frac{\pi}{16} \bar{c}^3 R \int_0^1 \hat{c}^2(\hat{r})\mathrm{d}\hat{r}$$

"2-Dimensional motion in an inviscid fluid, the first term was calculated for each blade element and integrated along the span of the wing" thus providing an estimate 3-D forces on the airfoil (Sane & Dickinson, 2002).

$$F_{\mathrm{trans}} = \frac{\rho S U_t^2 \hat{r}_2^2(S)}{2} [C_{Lt}^2(\alpha) + C_{Dt}^2(\alpha)]^{1/2}$$

Quasi-steady transitional estimate for the net force was developed through vector addition of lift & drag estimates (Sane & Dickinson, 2002).

ARSI
Aerospace Research Systems, Inc.

Wing Geometry & Aerodynamics: Computational & Physical Aspects

Completed three experiments to evaluate the capability of the Neurogenesis Algorithms to recognize flapping wing motion. 2- and 3-Dimentsional algorithms were used.

ARSI
Aerospace Research Systems, Inc.

Wing Geometry & Aerodynamics: Computational & Physical Aspects

ARSI
Aerospace Research Systems, Inc.

Wing Geometry & Aerodynamics: Computational & Physical Aspects

NiTi

Nitinol (NiTi-55% nickel + 45% titanium) belongs to a class of materials called Shaped memory Alloys (SMA)

Shaped Memory Effect (SME) allows the alloy to remember a particular shape. Once a shape has been remembered, the alloy may be bent out of shape. Then returned to its original shape by heating the alloy to its transition temperature.

ARSI
Aerospace Research Systems, Inc.

Wing Geometry & Aerodynamics: Computational & Physical Aspects

NiTi Physical Properties:

Tensile Strength --- 200,000 psi
Melting Point --- 1,250C (2,282 F)
Resistance --- 1.25 ohms per inch (.006 wire)
Corrosion Resistant

Wing Geometry & Aerodynamics: Computational & Physical Aspects

The NiTi alloy has nearly equal amounts of both metals.

However changing the ratio will significantly effect on the transition temperature.

A 1-% difference in the ratio varies the transition temperature from -100 to +100 C.

NiTi wire in our experiment has a transition temperature of 70C.

ARSI
Aerospace Research Systems, Inc.

Wing Geometry & Aerodynamics: Computational & Physical Aspects

The generated reverting force for one square inch of NiTi is + 30,000 PSI.

NiTi-Flexinol® wire (Dynalloy Inc.) is used as an actuator material. Flexinol wire can last 1,000,000 cycles whereas othre NiTi alloy wire that may last 1,000 cycles or less. 15-mil Flexinol wire has a rated contractive force of 1.786 kg (4 lbs.)

Wing Geometry & Aerodynamics

Major Issues:

Flutter and Vibration.

Dynamic stability.

Adequate control feedback.

Complex Functional Nanostructures

Los Alamos National Laboratory
Center for Integrated Nanotechnologies (CINT)

Definition:

Complex and collective interactions between individual components in materials to yield emergent properties

Complex Functional Nanostructures

- Complex Functional Nanomaterials
  - Interactions between individual components, properties and functions.
- Nanomechanics
  - mechanical behavior of nanoscale materials and structures
- Computation & Simulation
  - computational methods and advanced computer simulation to develop and define a new class of function structures.

Complex Functional Nanostructures

Force interactions on the wing structure by the mechanically functional components.

Embedded carbon nanotubules or deposited NiTi structures.

Substrate interactions and fatigue.

Delamination of thin film stacks.

ARSI
Aerospace Research Systems, Inc.

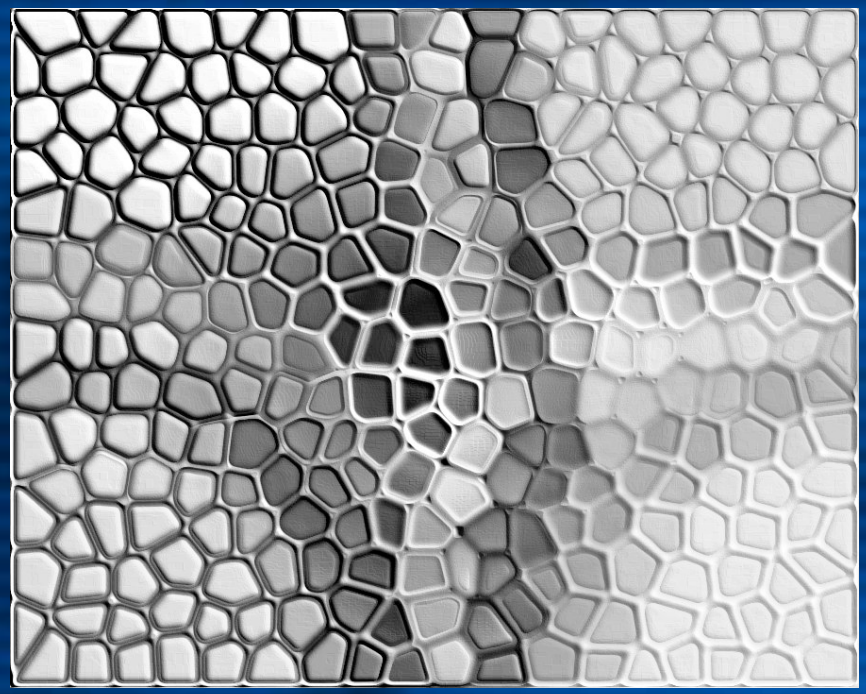
Complex Functional Nanostructures

Example of Enabling Technologies

IR photovoltaic nanotechnology from the University of Toronto, 4nm cells produce nearly the same efficiency per area as UV solar technology.

ARSI
Aerospace Research Systems, Inc.

Complex Functional Nanostructures



Graphic by ARSI simulating IR photovoltaic system with proprietary frequency and wavelength selective coating.

Concept of the IR solar technology coated with a selective coating varying UV & IR radiation according to component application in the substrate.

ARSI
Aerospace Research Systems, Inc.

ARSI Sophia Technology Applications

- Dropsonde Sophia Cloud Rider System
- A-Neural Membrane Ion Thrusters
- And future applications.

ARSI
Aerospace Research Systems, Inc.

ARSI Sophia Cloud Rider ©

Near Term Applications (5-10 years)

Global Environmental Monitoring System (GEMS) Concept

ARSI Sophia Cloud Rider GEMS Concept

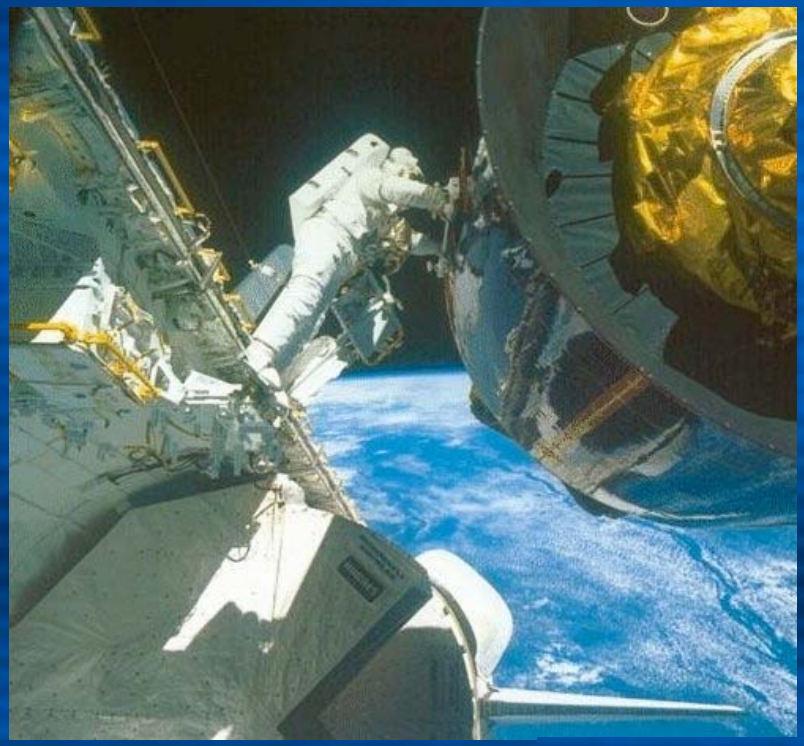
- Dropsonde system long-duration weather monitoring.
- Proliferant emissions detection, homeland security and defense missions.
- Geo-Environmental and atmospheric health monitoring.

Covers large area through dispersion canister. Uses the physics of clouds to “hitch” a ride.

ARSI Sophia Technology Applications

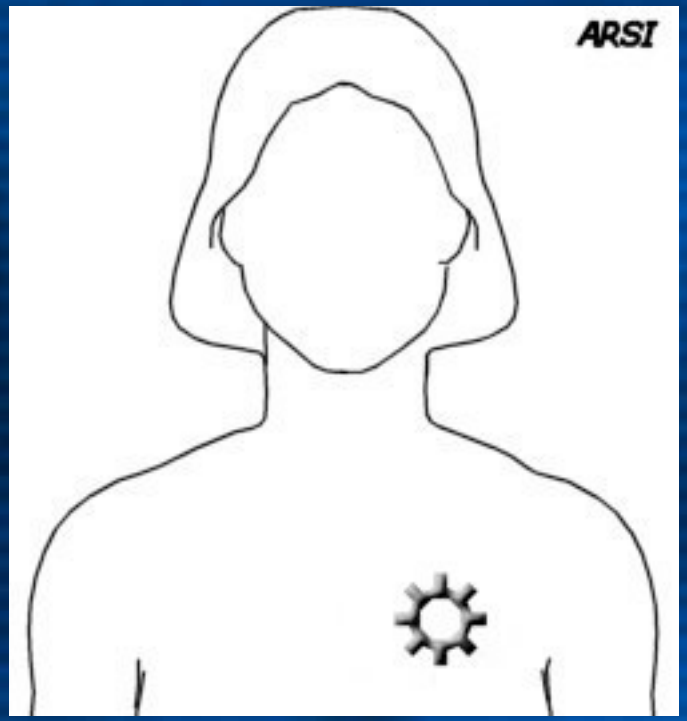
Current US space suits do not provide protection against electrical shock, radiation or crush injuries.

ANM functional structures using deposited alloys and/or carbon nanotubules will provide greater protection and act as an assistive system with adaptive geometry actuators, etc.



ARSI
Aerospace Research Systems, Inc.

ARSI Sophia Technology Applications



Remote physiological and environmental monitoring of astronauts.

Some Applications:

-Telemedicine reporting system.
- Improved countermeasures effectiveness.
- Radiation dosimetry.

ARSI
Aerospace Research Systems, Inc.

ARSI Sophia Technology Applications

Future systems:

Advanced A-neural functional structures:

Artificial organs, board level and membrane enzyme and protein production, membrane satellites and mirrors, and space habitats.

ARSI
Aerospace Research Systems, Inc.

ANM Flapping Wing Phase I

Thanks to the NASA Institute for Advanced Concepts for funding revolutionary ideas.

ARSI
Aerospace Research Systems, Inc.