16.982 Bio-Inspired Structures
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Bio-Inspired Structures

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Why Take This Course? Bio-Inspired Structures

Course Objective...

Introduce fundamental concepts to Bio-Inspired Structures

You will learn about:

- Development and Characterization of Bio-Inspired Structures
- Bio-Inspired Morphing Structures
- Bio-Inspired Nano Structures
- Bio-Inspired Intelligent Structures
- Novel Bio-Inspired Device Concepts

This course will help you to:

- Use Bio-Structures for Engineering Design
  - Realize new design opportunities with Novel Materials

COURSE MATERIAL

Required text:

- There is no basic text book for the course due to the interdisciplinary nature of the topics covered. Course handouts, suggested reading, and presentation from invited guest speakers covers most lecture topics.
- Materials Selection in Mechanical Design, Michael F Ashby, Elsevier, 2005

Optional Material:

- Stealing Ideas from Nature, JFV Vincent, Springer, 2001
- Biomimetic Synthesis of Nanoparticles. In *Encyclopedia of Inorganic Chemistry* Slocik,J.M.; Knecht, M.R.; John Wiley and Sons Ltd New York NY, 2005

GRADING

You will prepare a literature review on a topic related to bioinspired structures. Confirm the topic area of the literature review with the course instructors and submit to me by Lec #7.

The research proposal should:

i) Summarize the state of knowledge of the topic,

ii) Identify critical unresolved science and/or technology issues, an

iii) Propose specific new research, for a 3 year period, to resolve these critical issues.

GRADING

The proposal text should be organized as follows:

1. Cover Page (with title of proposal and names of co-authors).
2. Executive Summary (1 page)
3. Introduction and Background (7-10 pages)
4. Critical Unresolved Issues (5 pages)
5. Proposed Research (10 pages)
6. References (numbered sequentially as they are cited in the text)

GRADING

The grade will be as follows:

- ✓ 25% on homework and participation,
- ✓ 25% for quizzes, and
- ✓ 50% on the research proposal and oral presentation

You will prepare a 25 minute presentation of your research and literature review, to be conducted on at the end of the semester.

The presentations must be prepared as power point slides. Five minutes of questioning will follow each presentation

Tentative Invited Guest Speakers

Professor Mary Boyce, MITMECHE

Professor Christine Ortiz, MIT, Materials

Professor Paul Lagace, MIT, Aero-Astro

Professor Brian Wardle, MIT, Aero-Astro

Professor Wole Soboyejo, Princeton University

Spacecraft: Material & Launcher Structures

Developments for RLV

- CFRP Thrust Frame
- CFRP Intertank Structure
- CFRP LH2 Tank and Lines
- CMC Nose Cap
- CMC Leading Edge
- CMC Elevon

Generic composite structures

Envisaged Materials Evolution

- low Cost processes and materials
- advanced welding techniques
- composite booster cases
- other improvement are foreseen but not in the composite materials field

Advanced composite structures

- Ti-CFRP, Al-GFRP
- Advanced CMC, C/C
- Fibre-metal laminates
- Composite health monitoring systems

Nano-composite materials

Archaeopteryx Lithographica (150 million years old)

Fossil image and artist rendering of archaeopteryx lithographica removed due to copyright restrictions.
Reece, Jane, and Neil Campbell. *Biology*. 6th ed. San Francisco, CA: Benjamin Cummings, 2001. ISBN: 9780805366242.

The fossil is from the Solnhoefen Limestone (Jurassic) of Germany

The first known bird

Archaeopteryx Lithographica (continued)

Artist renderings of archaeopteryx lithographica removed due to copyright restrictions.

May evolve from small, warm-blooded coelurosaurian dinosaurs

Features: highly asymmetrical primary feathers associated with flight (camber)
good glider, short flights among trees using long tail for control and stability
wing flapping (pectoral muscle),

Natural selection played important role in refining the wings. Type of habitat a flying animal lives in and the way it exploits that habitat are closely related to its body size, wing form, flight style, and flight energetics.

Image from FirstPeople.us.

Image by hickoryhollow113 on Flickr.

Image by wwarby on Flickr.

Image by Lip Kee on Flickr.

Wing Structure

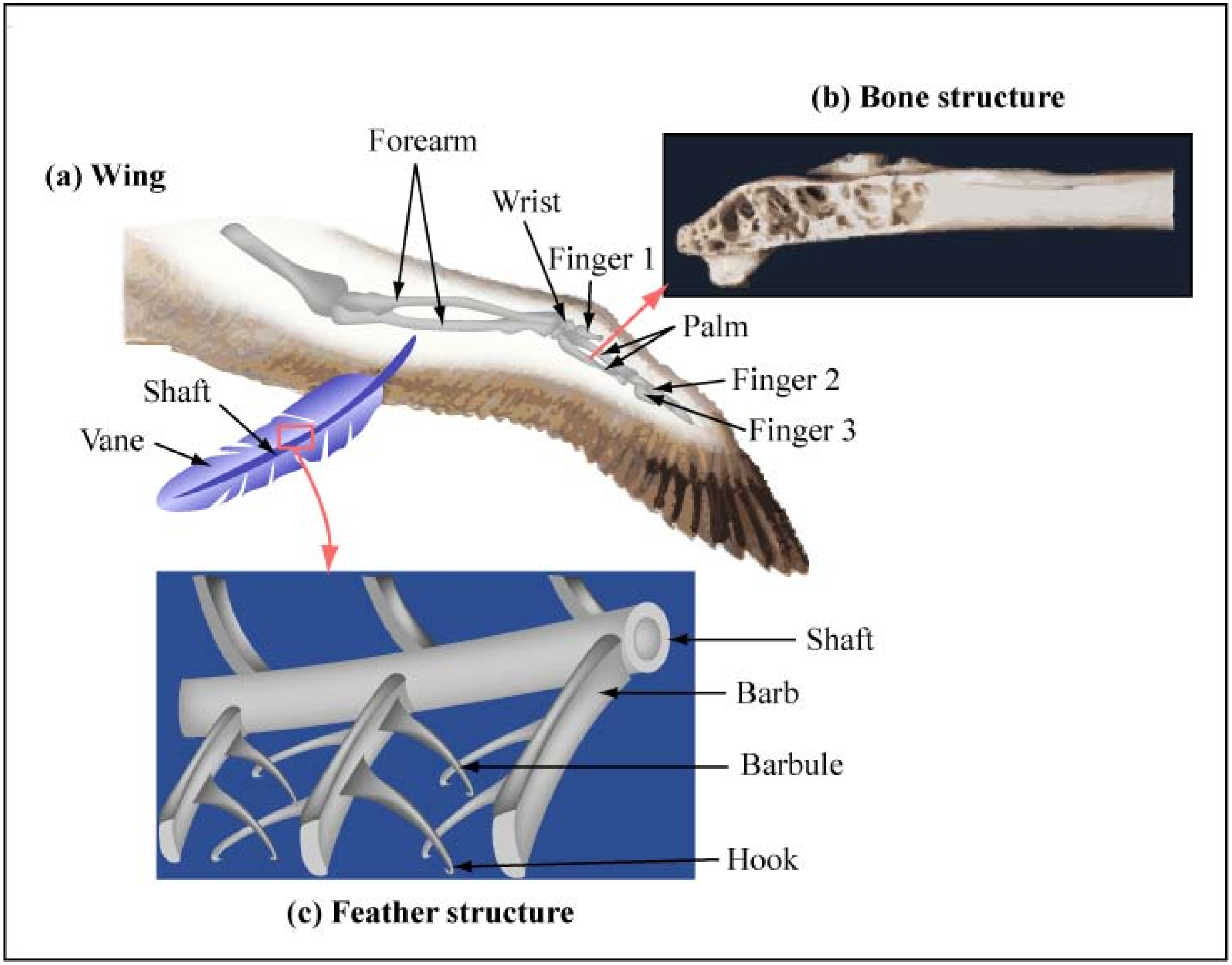


Figure by MIT OpenCourseWare.

History of flight

- Icarus (Greek mythology)
- Leonardo Da Vinci observed birds for twenty years and designed bird-like flying machine.

Wright Brothers (Dec. 17, 1903)

- Before their successful flight, they observed birds to study their mechanisms of flight. They determined they needed to adjust the angle at the end of their wings for control, mimicking how birds bend their outer feathers. In order to achieve angle adjustment, they used a mechanical wing warping method. Through a series of wires and pulleys they were able to control their airplane. As aviation progressed ailerons, rudders, and elevators replaced the Wright brother's method of pulling wires.

Diagram of Wright Brothers flyer removed due to copyright restrictions.

Biological materials and systems exhibit complex functionality, are composed of nano-scale components and have evolved to work.

Images removed due to copyright restrictions.

Nature combines hard and soft materials often in hierarchial architectures to get synergestic, optimized properties and combinations of properties →useful functionality.

Goals:

- Emulate proven biological designs
- Develop new properties by nanostructuring
- Impart responsive life-qualities to robust engineering materials
- Integrate on meso and macroscales →FILMS

CHALLENGE: How to controllably organize multiple (hard/soft) materials on multiple length scales

Smart Joint Mechanism – A Departure From Biology

Images removed due to copyright restrictions.

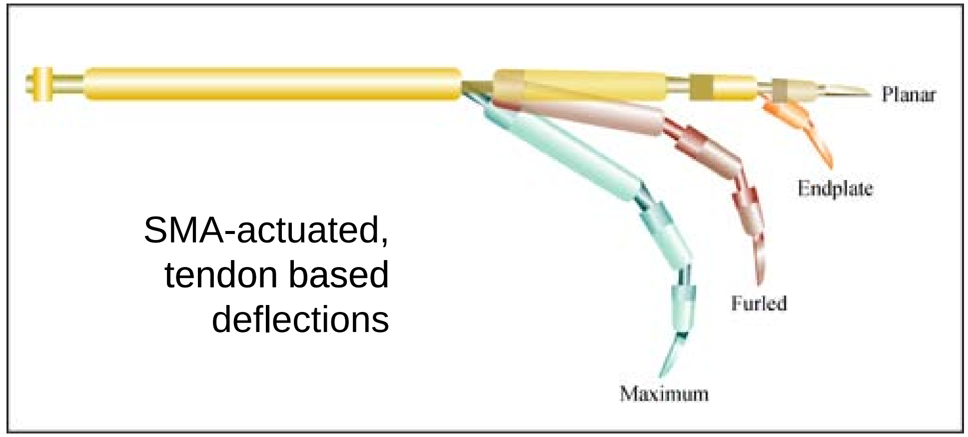


Figure by MIT OpenCourseWare.

Inspired by shore bird morphing wing studies and energetic inefficiencies, the Smart Joint will provide actuation and an actively rigid structural member in a low profile envelope without the need for tendon actuators

Composite of SMA, SMP, nichrome to decouple heating

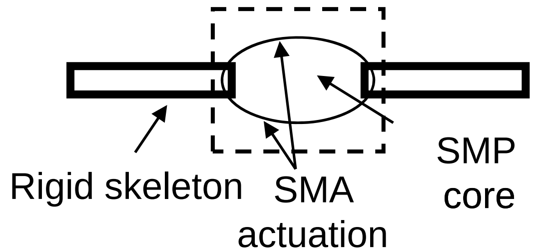
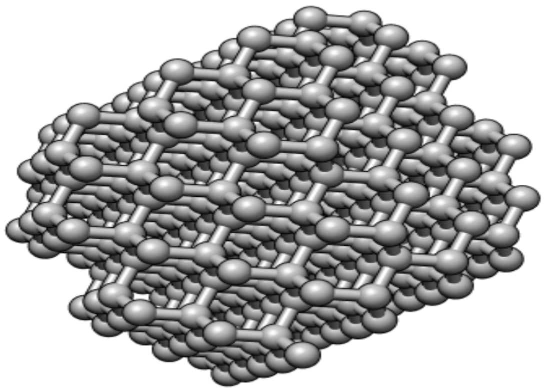


Figure 6 from http://lims.mae.cornell.edu/projects/batwings.html

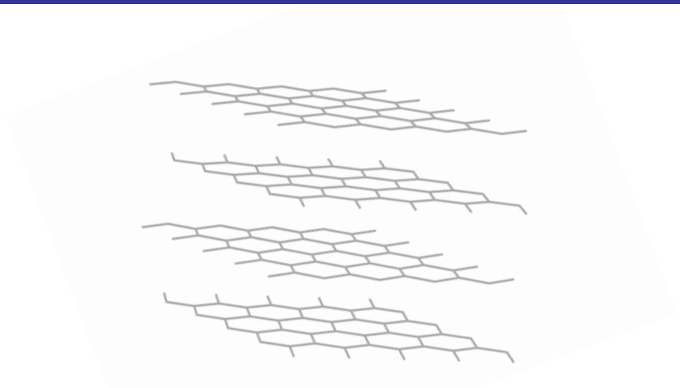
Three step heating/cooling process to transition between cooled states

Figure 5 from http://lims.mae.cornell.edu/projects/batwings.html

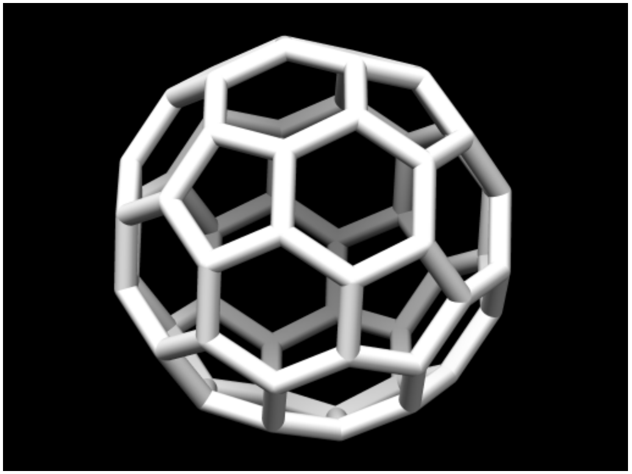
Biomimetics and nanotechnology



Diamond. Each carbon atom is bonded to four others in a tetrahedral fashion.

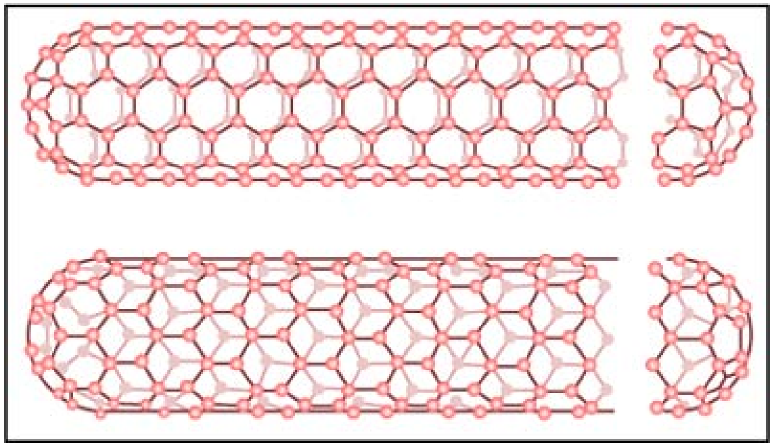


Graphite. The ball and stick model of graphite indicates the closely-packed nature of the carbon atoms. The layers of carbon in graphite are 335 pm apart, approximately twice as long as the C-C bond distance of 142 pm.



C60 Buckyball.

Figure by MIT OpenCourseWare.



Carbon nanotube. The molecules vary in length from a few nanometers to a micrometer or more.

Images courtesy of Open Chemistry

Structural Materials

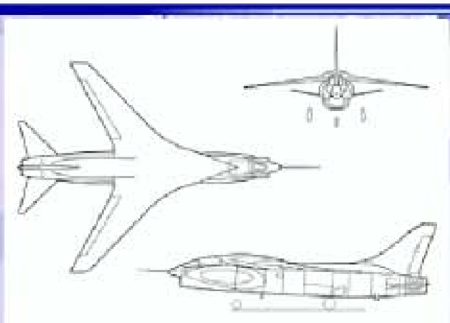
Problem:

"Structure" is parasitic to the mission. – It provides a platform for payload, sensors, communications, etc.

Solution:

- Eliminate
- Give structure other functions!!

Bio-Multifunctional Materials Concept



Functions designed in isolation
Components have a *single* function

Inspiration:
NATURE

Functions evolved in unison
Components are *multi*functional

Image by cotinis on Flickr. [http://www.flickr.com/photos/pcoin/3305948273/]

Nature achieves multifunctionality by <u>compositional and morphological</u> control at the "<u>material system</u>" level

Natural Multifunctional Material: An Example

<u>*Cuticle*</u>

A Hetero-nanostructured Material:

(Compositional & Morphological)

Chitin fiber (3 nm x 180 nm -- like glass fibers)
- orientation
- volume fraction

Protein matrix
- pH control
- water content control
- modulus control

Pore canals
- connection between epidermal cells and cuticle for communication and repair

Interlined holes
- filled with resilin
- campaniform sensilla

Multi-layered arrangement
- stiffer outer/softer inner layer

Design issues solved by Nature!
- Fiber orientation/placement
- Fiber matrix interaction based on chemical control of interfaces
- Holes/canals distribution without weakening structure
- Self-repair, growth
- Temperature control

Bio Inspired Structure Grand Challenge

Create material systems with optimized MULTI-functionality by design.

Materials Characteristics	
Mechanical	Stress - Strain
Thermal	Heat Flux - Temp. Gradient
Electric	Flux Density - Field Intensity
Magnetic	Flux Density - Field Intensity
Ballistic	Energy Density-HSR response
Repair	Self-organization/self assembly

Integration of diverse features/requirements into useful materials and design tools

Demonstration that multi-functionality provides a system benefit

Bio Inspired MFM – (Some) Questions

- How do we optimize functions in a multifunctional material?
- How do we capture the features (compositional, spatial, morphological) that control the functions of a particular material system?
  - Feature population/distribution. (Dominance of the extremes).
  - Coupled dependence of properties on material features.
  - Evolution of "anomalous"/defect structure.
- What mathematical techniques are available or need to be developed to enable "multifunctionality" by design?
  - Reducing complexity.
  - Incorporating variability in design.
- What processing techniques are available to synthesize multifunctional structures?

CHALLENGES

- To discover the physical bases for the evolution of functions (structural, electromagnetic, thermal, etc)
- To understand and be able to select for desired properties at the salient nano-, micro-, macro-structural level
- To elucidate the hierarchical organization that give rise to macroscopically apparent functions
- To develop ‘fast’ techniques for optimization of multiple functions

Premise: Build New Capability Within Structural Materials

Outstandingly successful

- Demonstrated a radical but sound concept
- Spawned a new field --- put "multifunctionality" on the map
- Carried out some of the very best materials science and technology
- Generated innovative and revolutionary material systems
- Achieved good transitions

End of the Day: Identified a Powerful Concept that can be Exploited during Implementation of our Materials Development Efforts.

Bio Structure: Power Fibers

Integrate power with structure

Robust energy source

Non parasitic

Transparent to user

Images of PowerFiber from http://www.darpa.mil/dso/thrusts/matdev/smfm/itn.html removed due to copyright restrictions.

Autophagous (Self-consuming) Structure

Image removed due to copyright restrictions.

Space systems

- Withstand mechanical loads during launch
- Convert into/consume as fuel on orbit
- Relocation of space assets for tactical operations
- End of life operations
- All solid or hybrid systems

UAV/UUV

- Utilize 'free' air/water
- Minimize residual presence