Bio-Inspired Structures

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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
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:


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.
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)
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
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

Developments for RLV
CFRP Thrust Frame
CFRP Intertank Structure
CFRP LH2 Tank and Lines
CMC Nose Cap
CMC Leading Edge
CMC Elevon

Nano-composite materials
Archaeopteryx Lithographica
(150 million years old)

The fossil is from the Solnhofen 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.
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.

Nature combines hard and soft materials often in hierarchial architectures to get synergistic, 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
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

Three step heating/cooling process to transition between cooled states

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

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.

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

Images courtesy of Open Chemistry
Problem:

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

Solution:

- Eliminate
- Give structure other functions!!
Nature achieves multifunctionality by **compositional and morphological** control at the "**material system**" level.
Natural Multifunctional Material: An Example

**Cuticle**

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.

<table>
<thead>
<tr>
<th>Materials Characteristics</th>
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<tbody>
<tr>
<td>Mechanical</td>
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<tr>
<td>Thermal</td>
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<tr>
<td>Electric</td>
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<tr>
<td>Magnetic</td>
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<td>Ballistic</td>
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<td>Repair</td>
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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

Autophagous (Self-consuming) Structure

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

Image removed due to copyright restrictions.