Diverse Applications of Engineering: From Attitude Control Systems to Characterization of Spider Silk

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North Dakota State University

Summer Internship Experience
Goddard Space Flight Center

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Time =  4485.00
 1 May 2016
GMT 122-01:14:45.00

POV
TRACK HOST
Fixed in
Boresight: +X
  Up Axis: -Z

Host
  World: Earth
Ref Orb: 0
    Frm: 0
    S/C: 0
   Body: 0

Range:      3.81
In Eclipse

Target
  World: Earth
Ref Orb: 0
    Frm: 0
    S/C: 0
   Body: 0

Range:      3.81
In Eclipse

   Show
 N Axes
 L Axes
 F Axes
 B Axes
 N Grid
 L Grid
 F Grid
 B Grid
 Gal Grid
 FOVs
 Prox Ops
 TDRS
x Shadows
 Astro Labels
 Truth Vectors
 FSW Vectors
x Milky Way
 Fermi Sky
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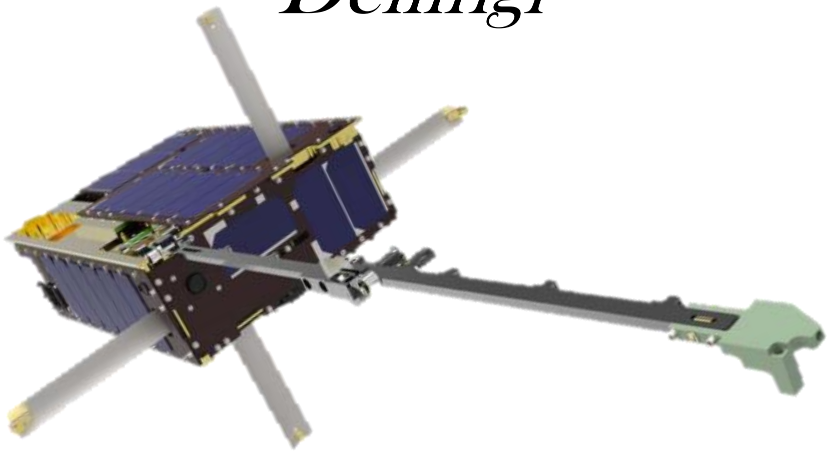
On-Board Orbit Propagation Model Verification of Dellingr CubSat Mission

Fall Fellowship Experience
Mechanical Engineering

Embedding Biomimetic Silk Fibers and Thin Films with Carbon Nanotubes (CNT)

Summer Internship Experience : Goddard Space Flight Center

Dellingr



On-Board Propagator

- Mimicking TRMM Orbit Determination
- Atmospheric Drag
- Gravity Model

Attitude Control Systems
Engineering Branch (591)

AETD
APPLIED ENGINEERING AND TECHNOLOGY DIRECTORATE
NASA GODDARD SPACE FLIGHT CENTER

Methods

1 Integration Into FSW

- Attitude Control Systems (ACS) main routine

2 42 and GMAT Simulations

- Testing and debugging
- Two-week duration simulations
  - Four main perturbing forces

3 Independent Run Routine

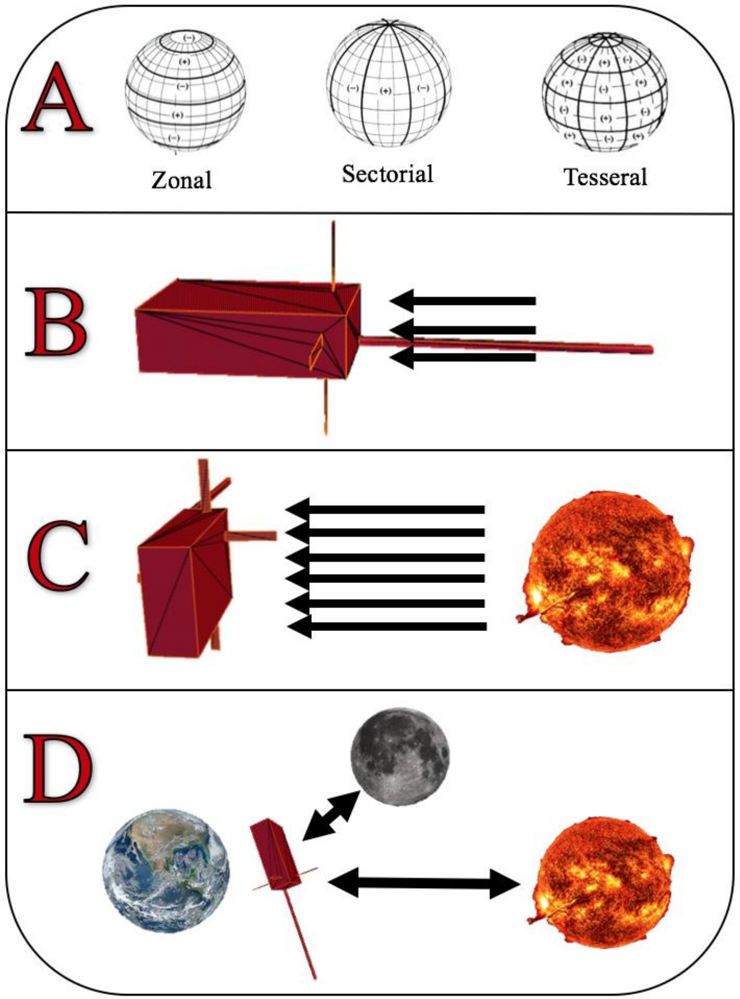
- Quicker run-time
  - Debug and validation testing

4 Validation and Enhancement

- On-board ephemeris to GMAT
  - Success, divergence < 200 Km
- Enhancement of gravity model

$$U(r) = \frac{\mu}{r}\left\{1 + \sum_{n=1}^{\infty}\left(\frac{R}{r}\right)^{n}\sum_{m-0}^{n} P_n^m(sin\lambda')[C_n^m cos(m\phi) + S_n^m \sin(m\phi)]\right\}$$

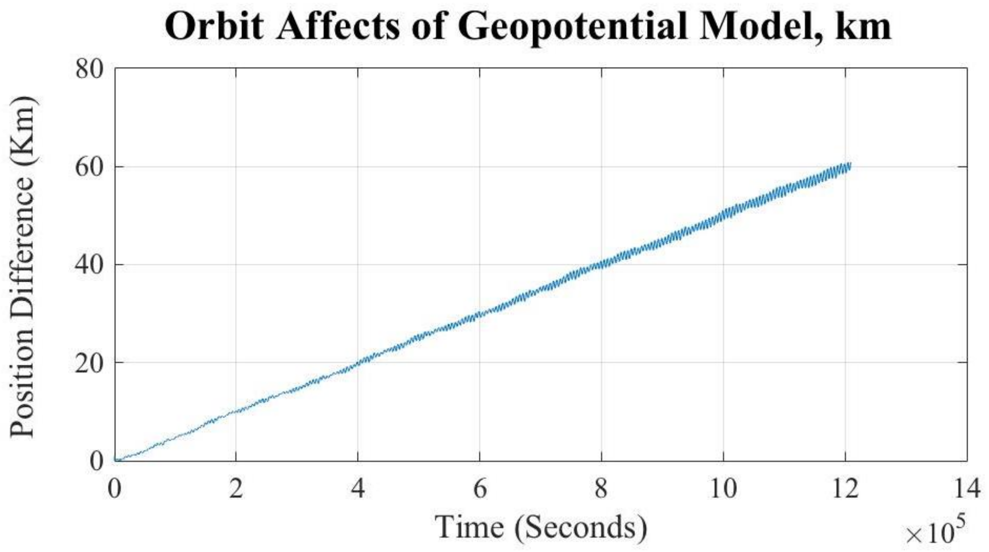
Perturbing Forces to Spacecraft Orbit[1]



A. Geopotential Modeling (J21 vs J4)
B. Atmospheric Drag (J21)
C. Solar Radiation Pressure (J21)
D. Presence of Sun/Moon (J21)

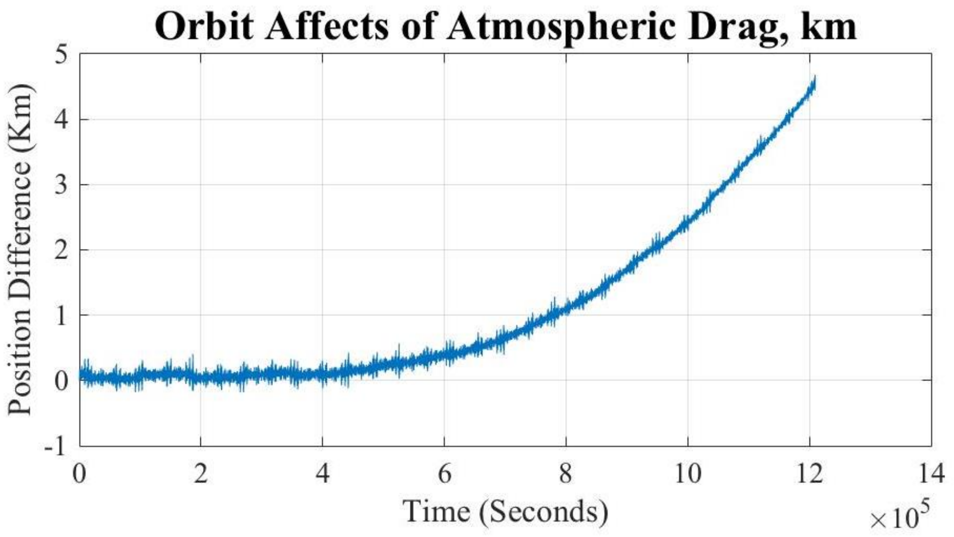
Results - GMAT

A



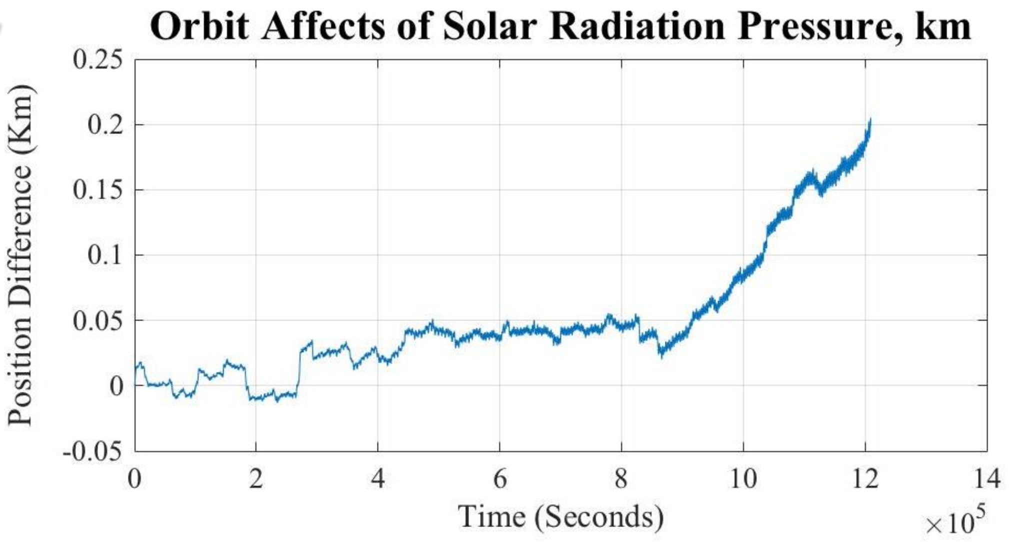
Orbit Affects of Geopotential Model, km

B



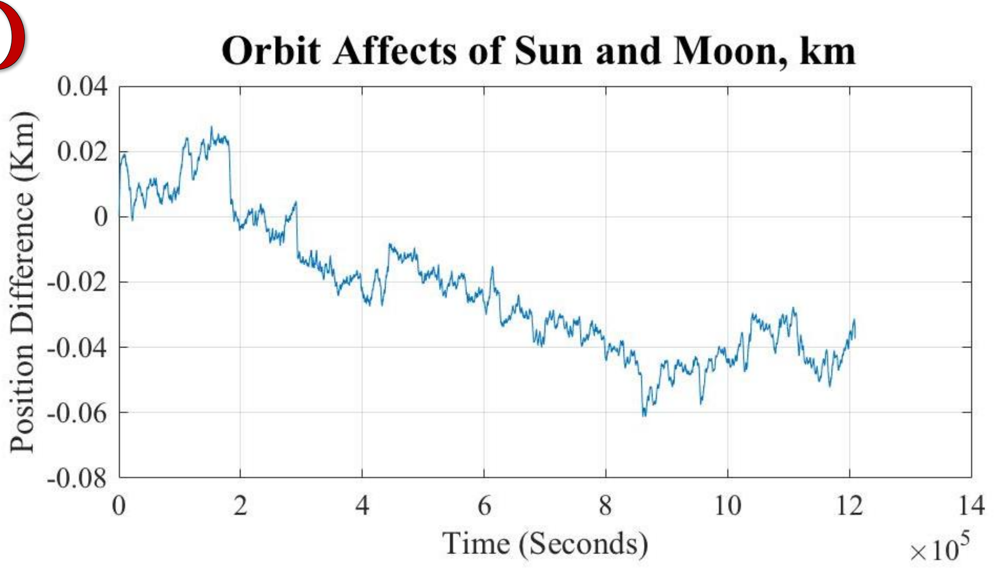
Orbit Affects of Atmospheric Drag, km

C



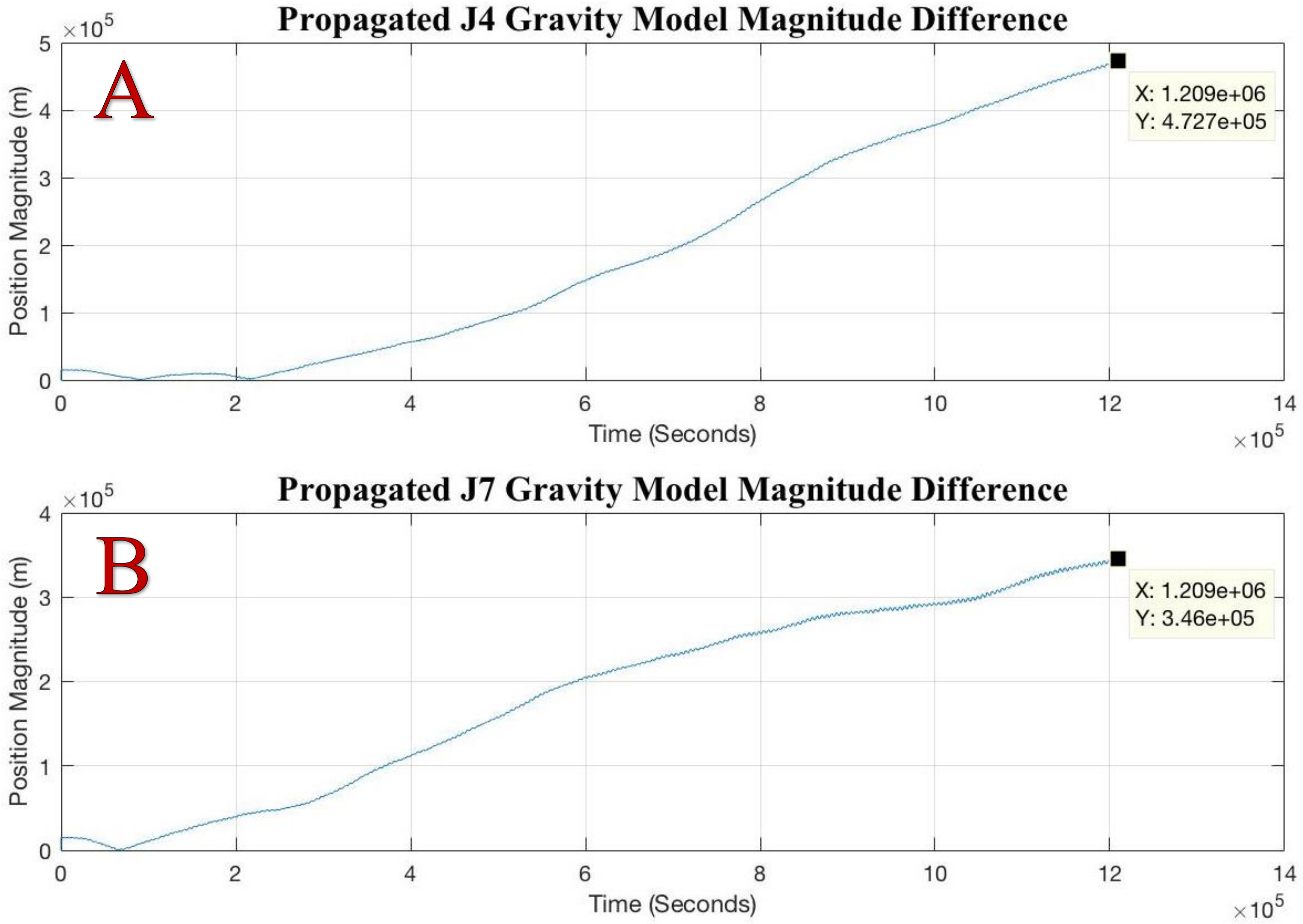
Orbit Affects of Solar Radiation Pressure, km

D



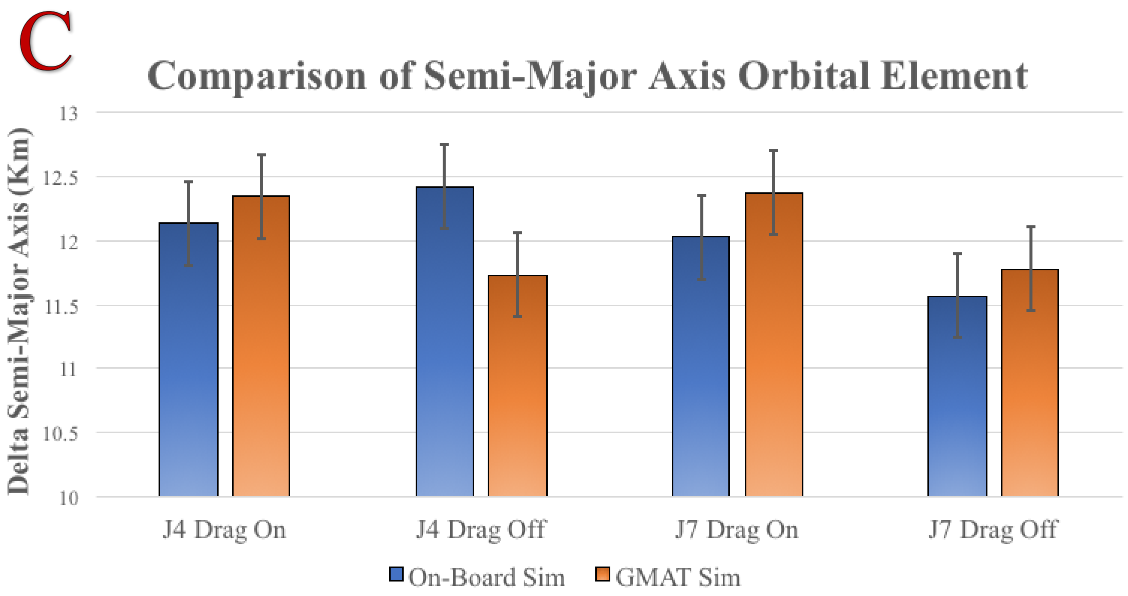
Orbit Affects of Sun and Moon, km

Results - Propagation



A. Magnitude difference of On-Board Propagator to GMAT (472.7 Km)
On-Board => J4 Gravity Model
GMAT => J21 Gravity Model

B. Enhanced gravity model repeated test **A** (346 Km)
On-Board => J7 Gravity Model
GMAT => J21 Gravity Model



C. Delta Semi-Major Axis
- On-Board J4 and J7 tests with and without Drag (Blue)
- GMAT J4 and J7 tests with and without Drag (Orange)

Discussion of Internship

- Spacecraft propagation integrated into Dellingr ACS main routine.
- On-Board J4 gravity Magnitude divergence of 472.7 Km after two weeks.
- Enhancement of gravity model decreased divergence to 346 Km.

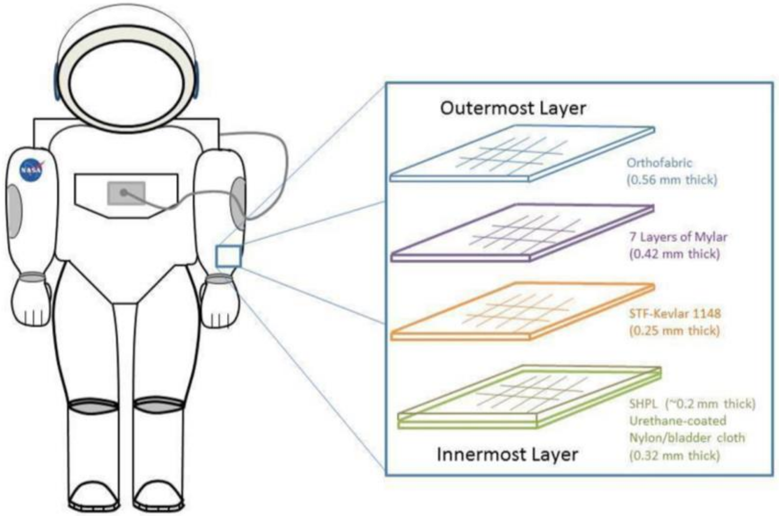
$$U(r) = \frac{\mu}{r}\left\{1 + \sum_{n=1}^{\infty}\left(\frac{R}{r}\right)^{n} \sum_{m-0}^{n} P_n^m(sin\lambda')[C_n^m cos(m\phi) + S_n^m \sin(m\phi)]\right\}$$

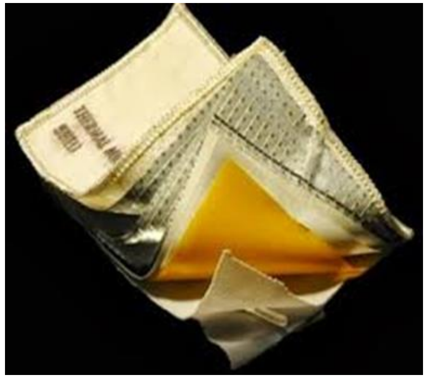
Fall Fellowship Experience : Mechanical Engineering

Golden Orb Weaving Spider
(*Nephila clavipes*)

Silkworm
(*Bombyx mori*)

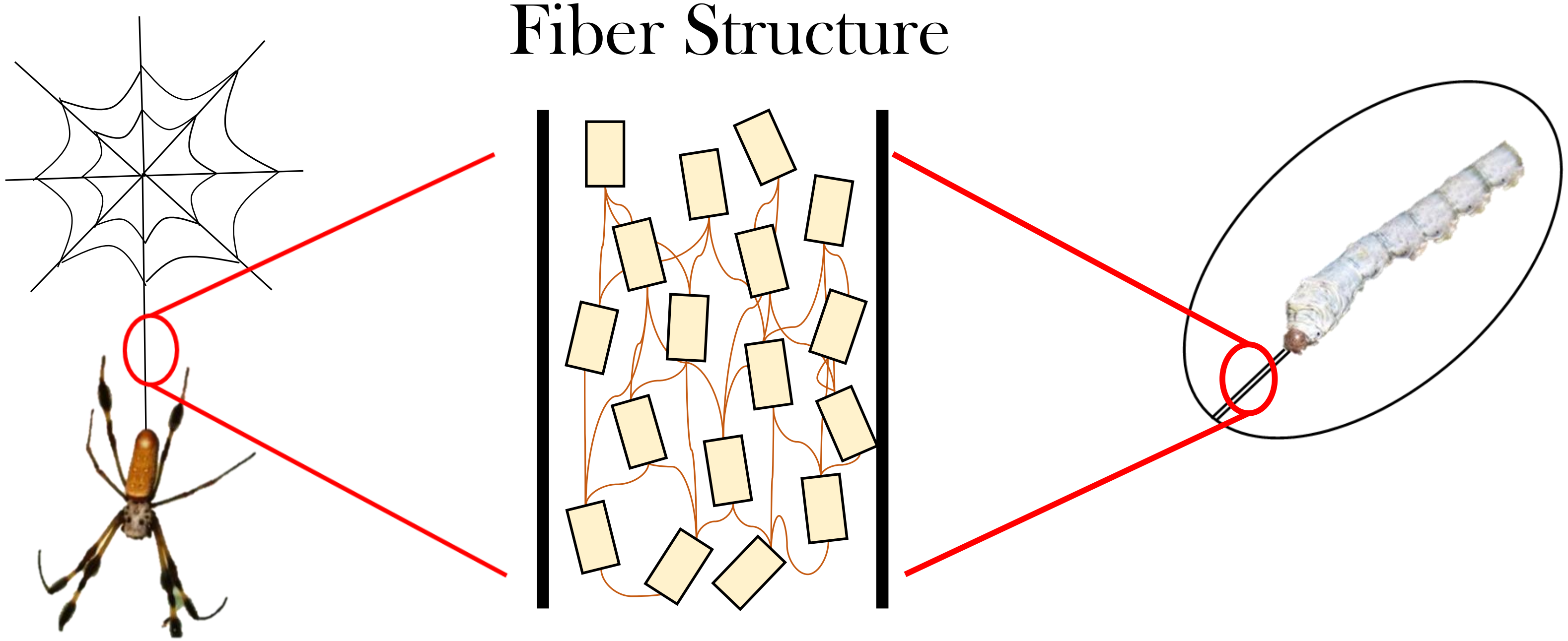
https://en.wikipedia.org/wiki/Bombyx_mori





Background

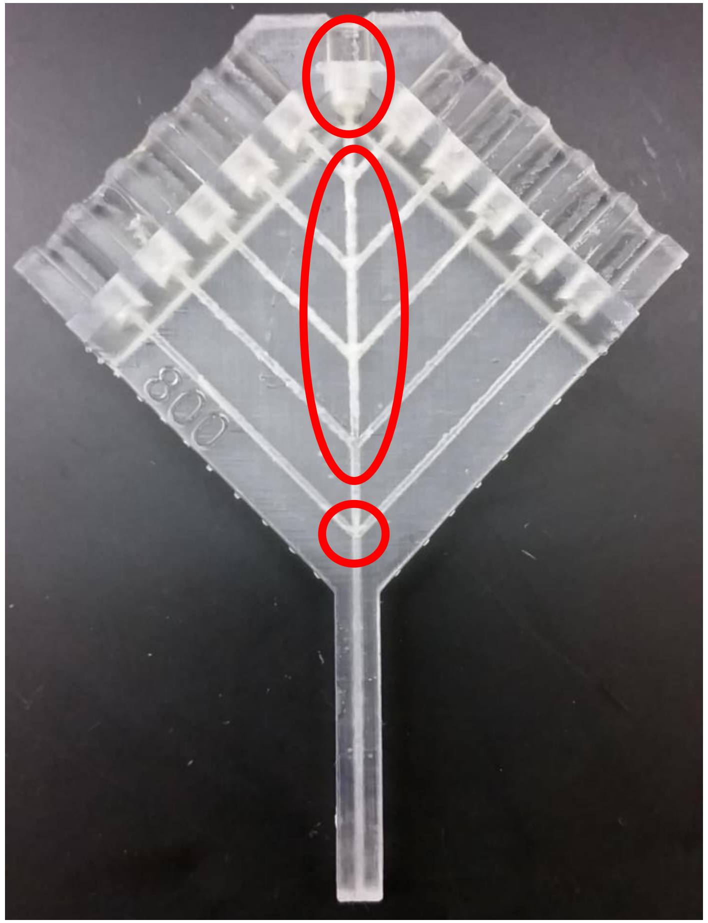
Fiber Structure



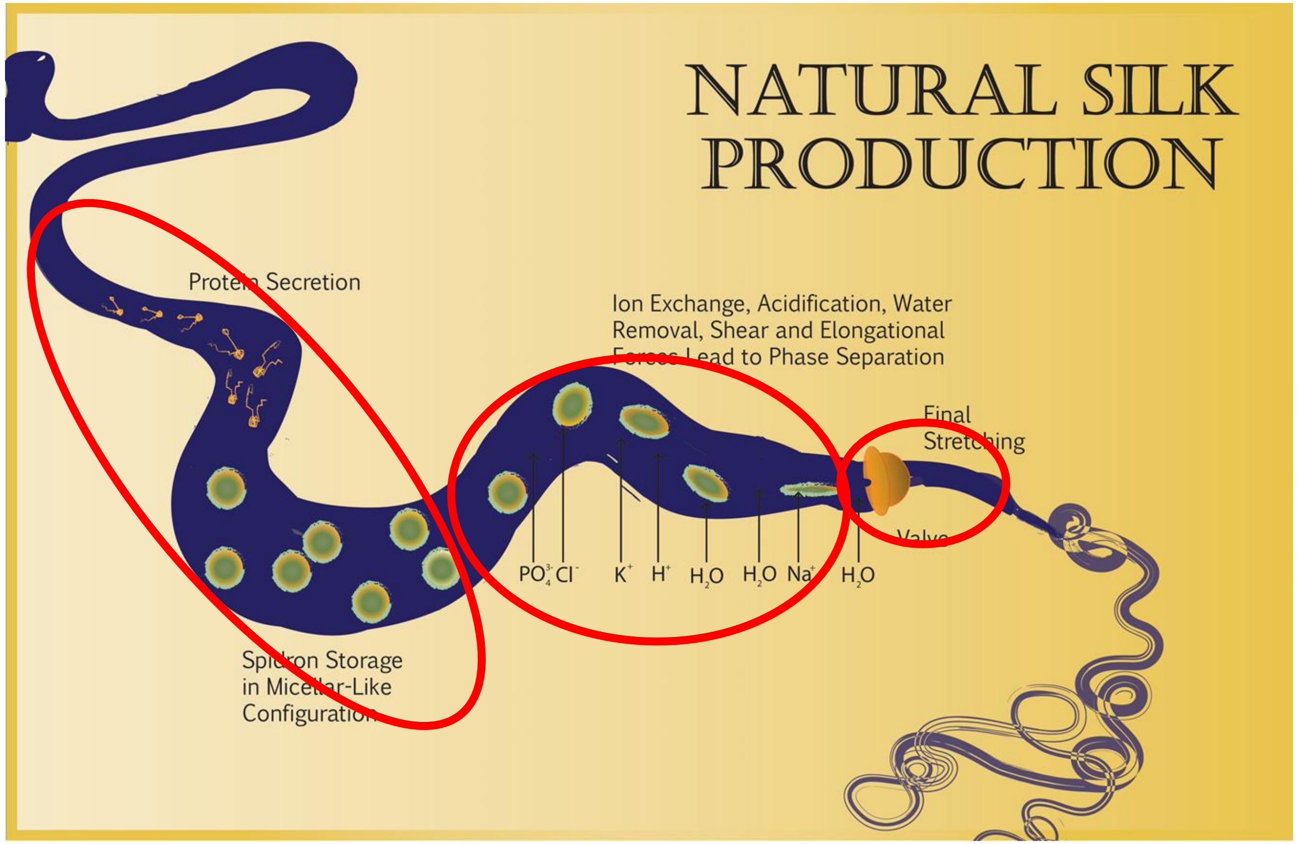
Material	Strength (GPa)	Strain (%)	Toughness (MJ/m^3)
Major Ampullate Silk	*1.5*	*21-27*	*136-194*
Silkworm Silk	*0.61-0.74*	*18*	*50*
Minor Ampullate Silk	0.92-1.4	22-33	*137*
Flagelliform	1	>200	75-283
Aciniform Silk	1.1	40	230
Kevlar	3.0	2.5	50
High-Tensile Steel	1.8-3.0	1.5-5	70
Nylon	0.75	18	70

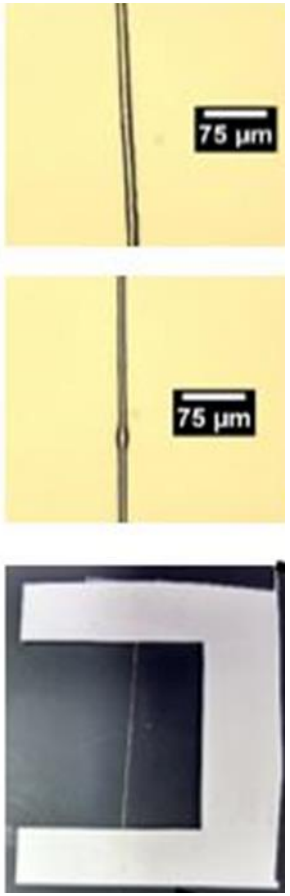
[2], [3]

Background



[4], [5]

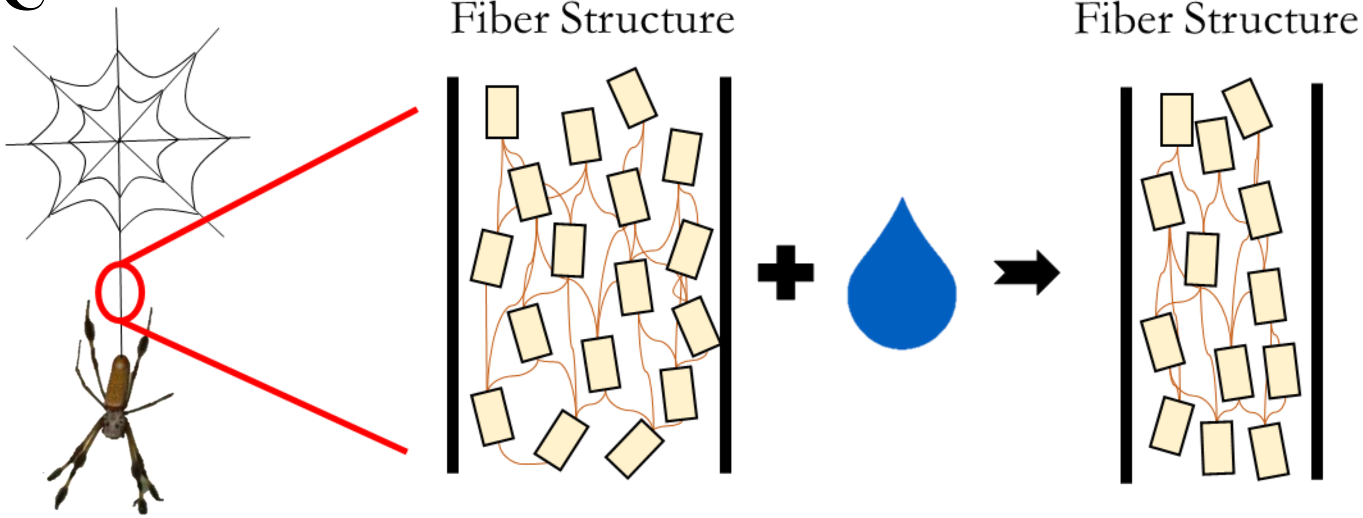




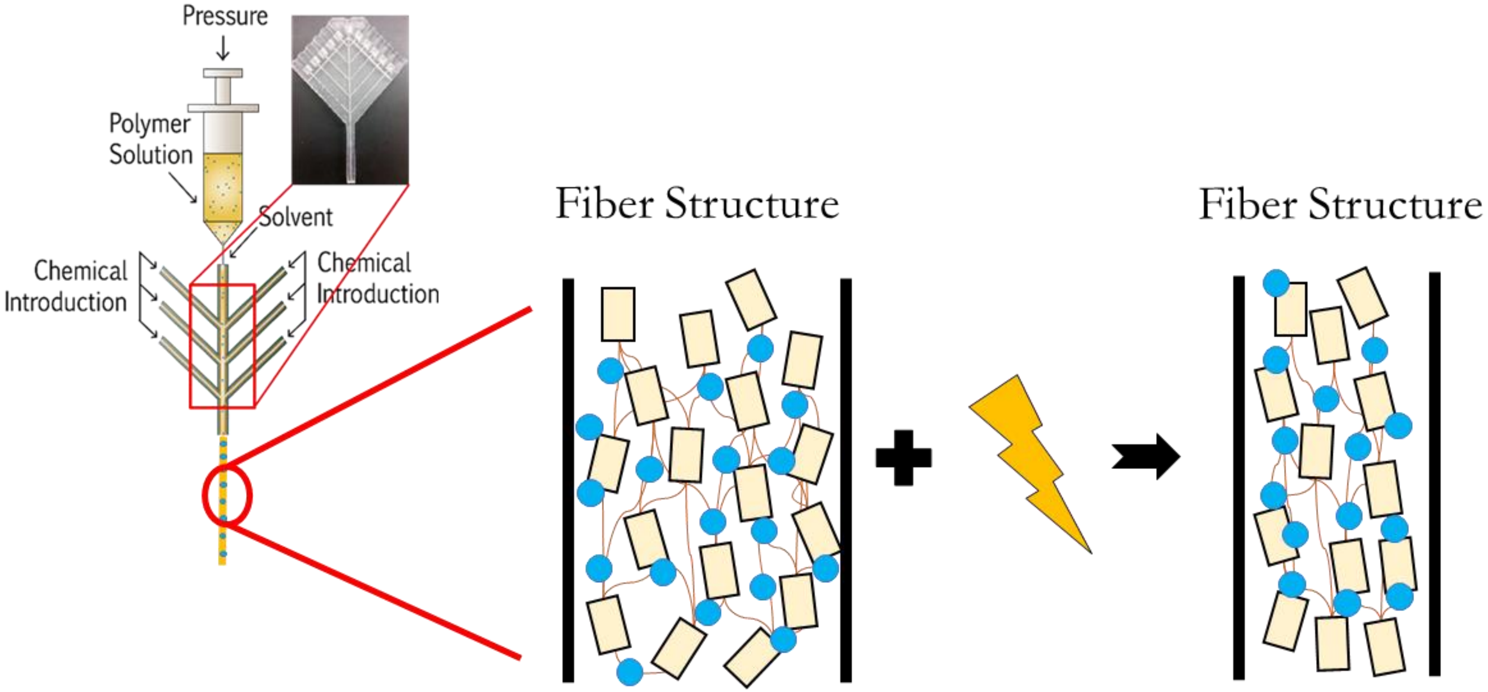
Response Characteristic

Super-contraction: Ability for the golden orb weaver's natural spider silk to contract up to 2/3 original length.

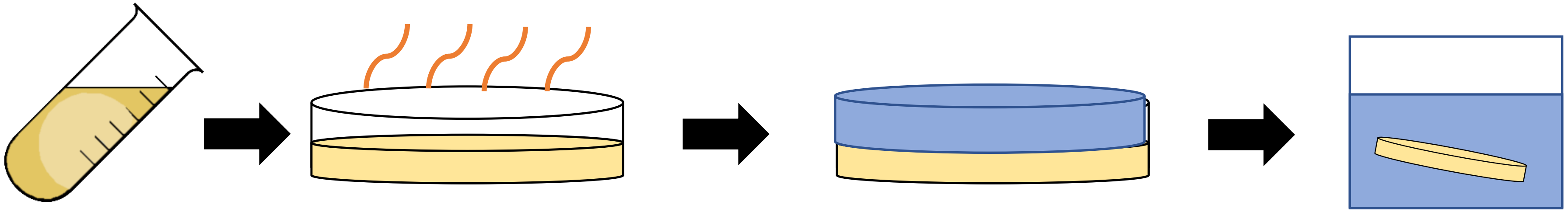
[6], [7]



- Nanoparticles:
  - Increase Conductivity
  - Increase Mechanical Performance

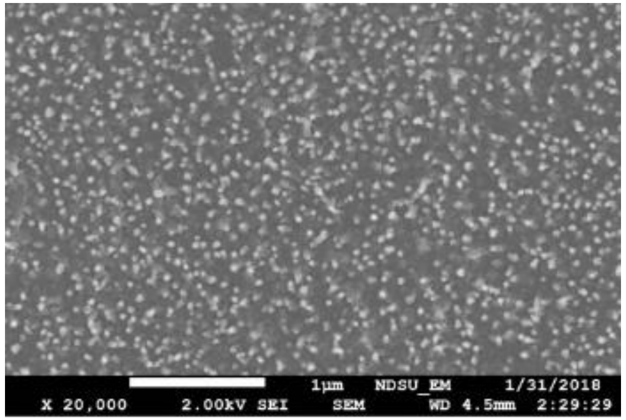


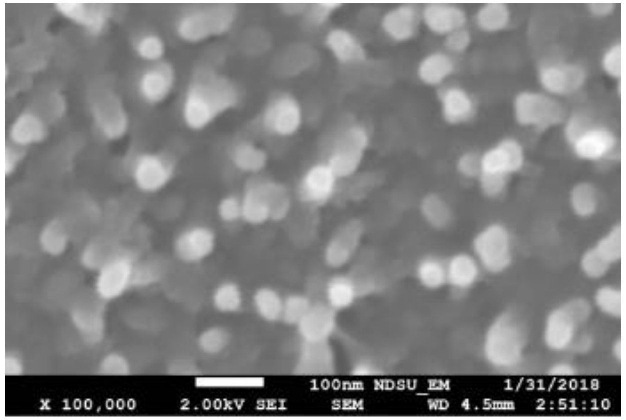
Methods

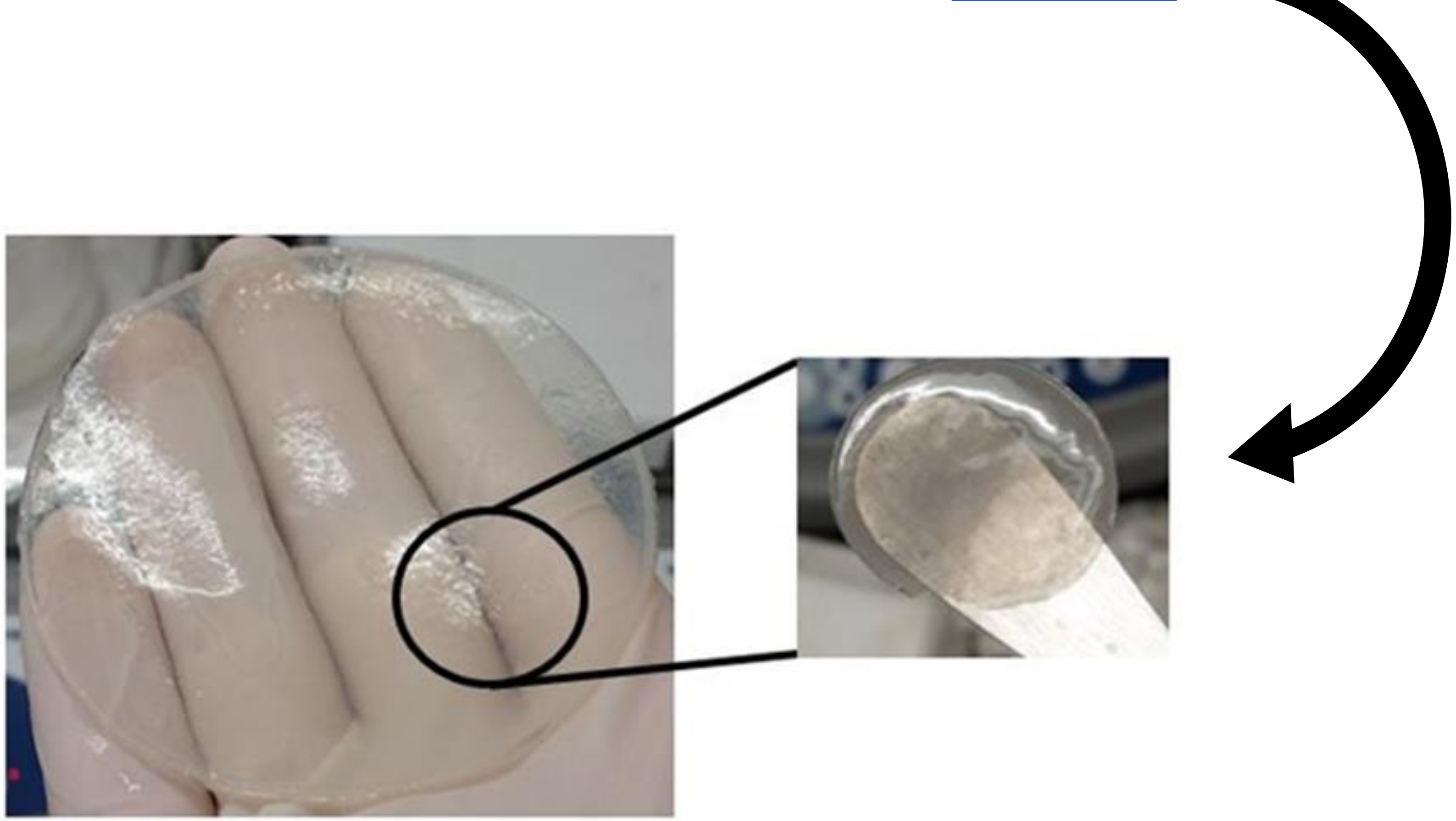


[8]

Formic Acid (FA) /
Calcium Chloride ($CaCl_2$)

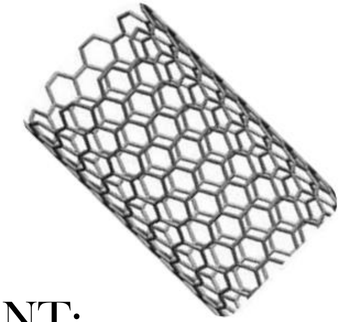






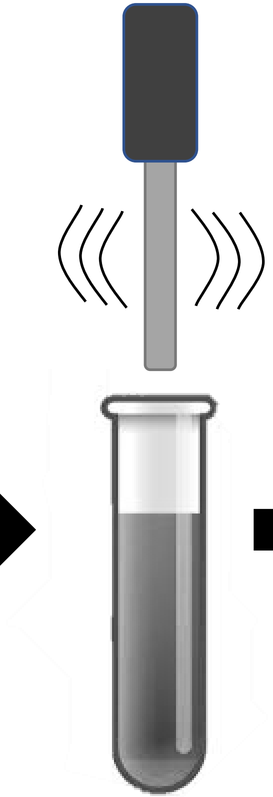
Methods

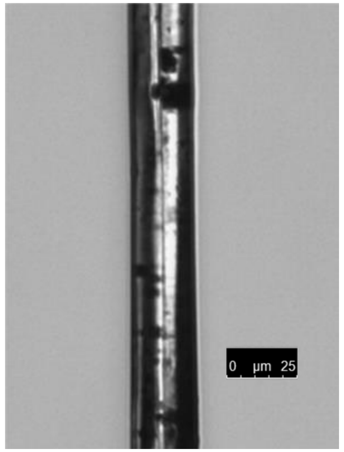
FA/$CaCl_2$

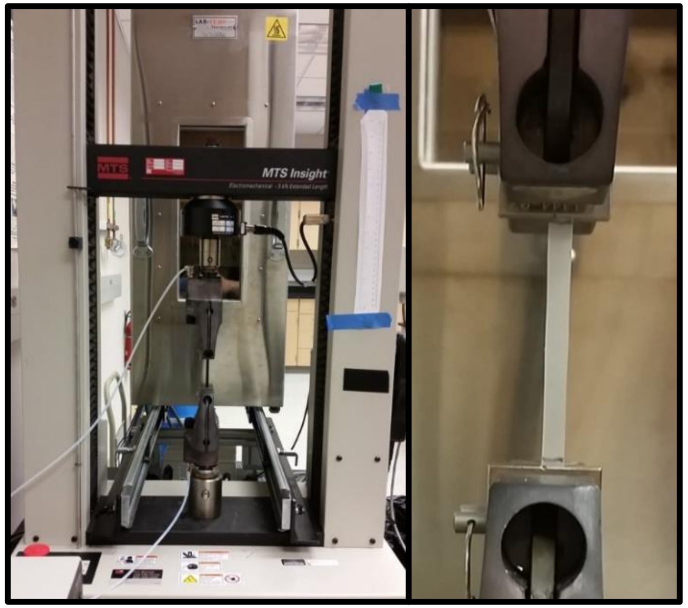


CNT:
Functionalized (COOH)
- Carboxylic Acid
Non-Functionalized

Sonication



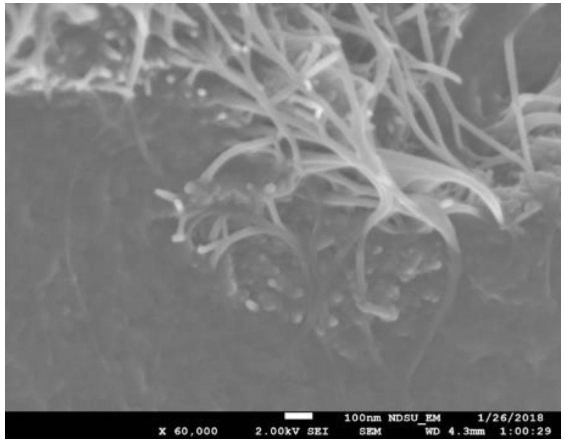


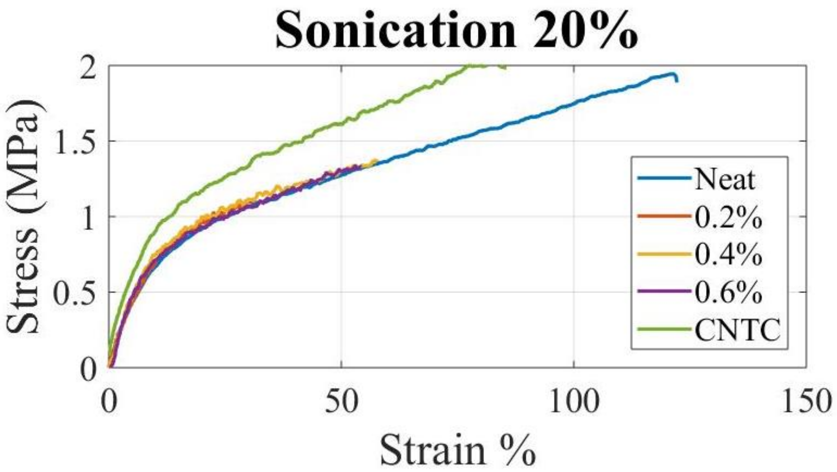


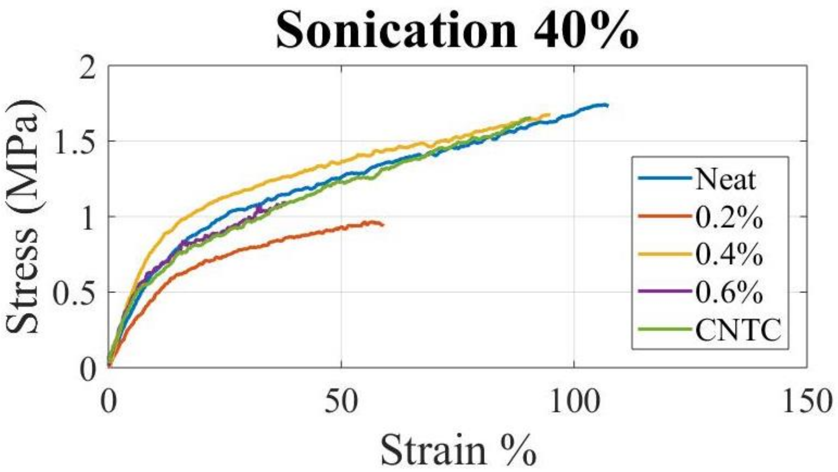
Mechanical Testing:

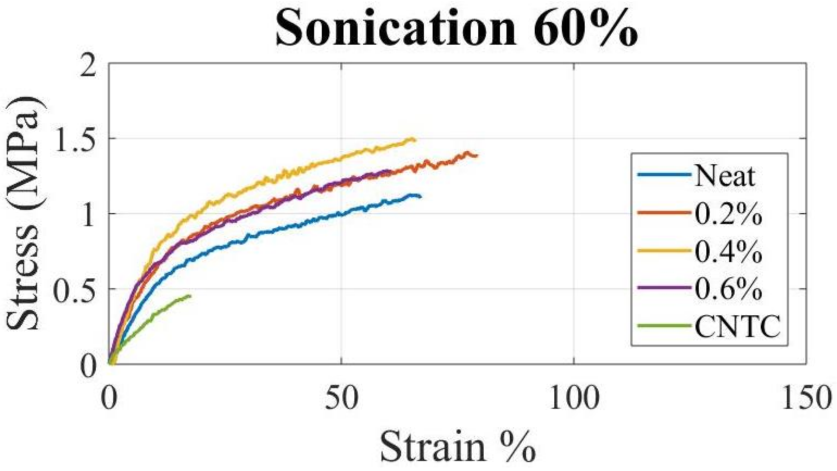
- Rate of Extension: 12.5 mm/min
- Gauge Length: 50 mm

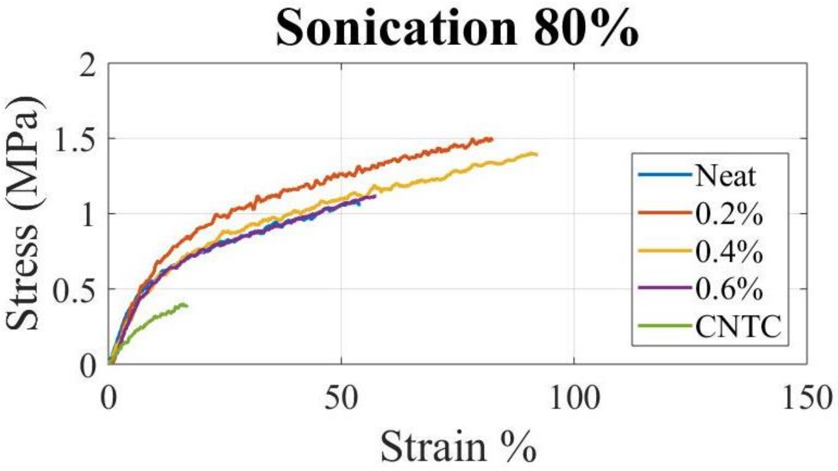
Results



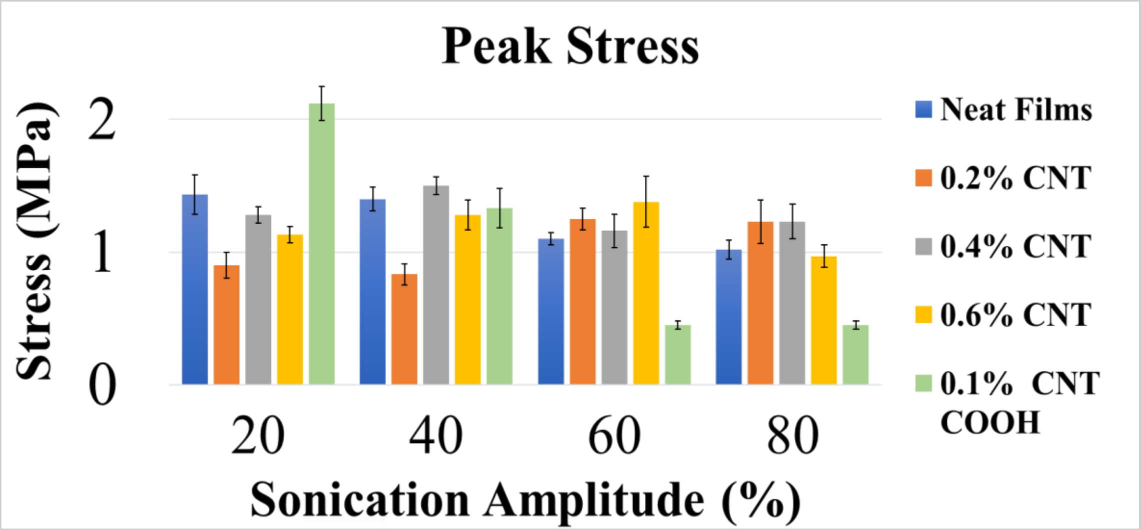

Sonication 20%

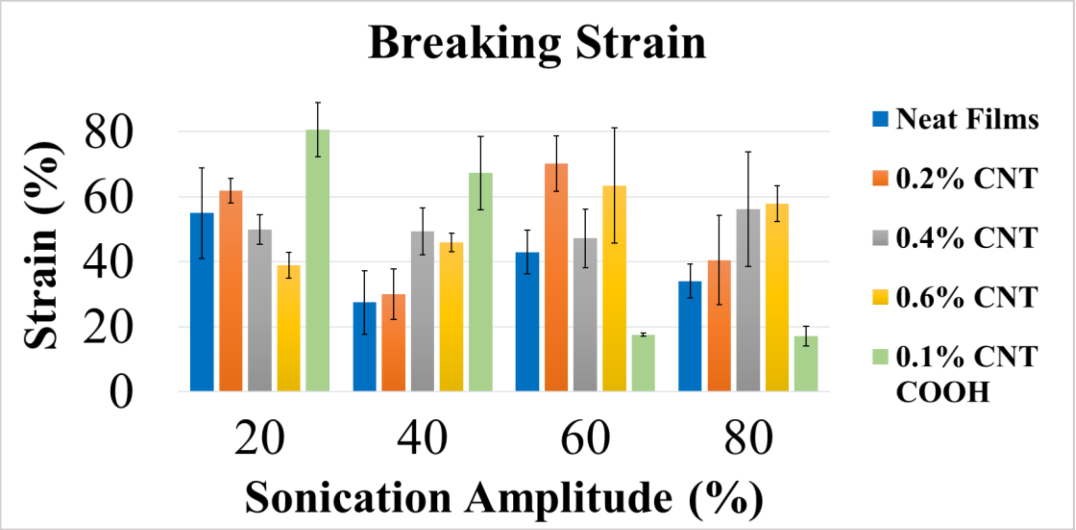

Sonication 40%

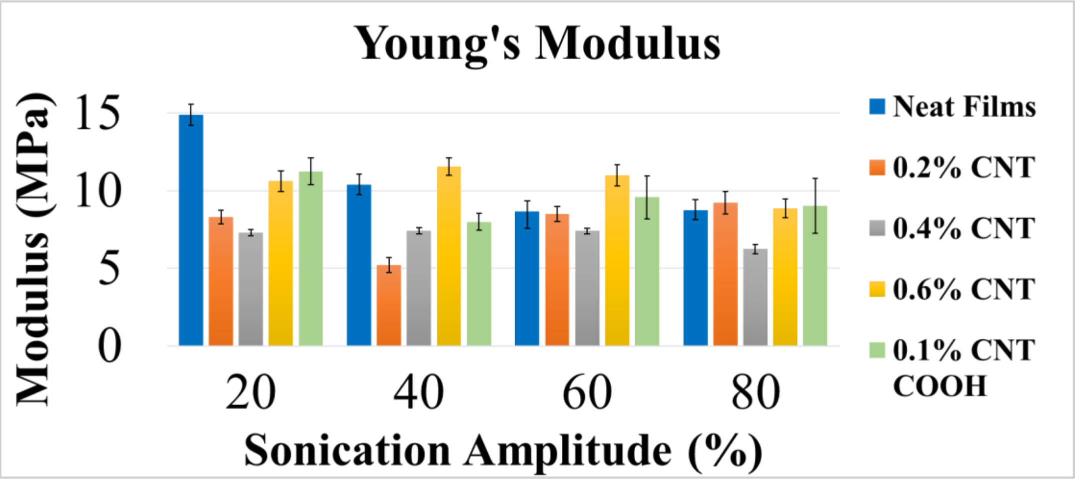

Sonication 60%


Sonication 80%

Results


Peak Stress
Stress (MPa)
0
1
2
20
40
60
80
Sonication Amplitude (%)
Neat Films
0.2% CNT
0.4% CNT
0.6% CNT
0.1% CNT COOH


Breaking Strain
Strain (%)
0
20
40
60
80
20
40
60
80
Sonication Amplitude (%)
Neat Films
0.2% CNT
0.4% CNT
0.6% CNT
0.1% CNT COOH


Young's Modulus
Modulus (MPa)
0
5
10
15
20
40
60
80
Sonication Amplitude (%)
Neat Films
0.2% CNT
0.4% CNT
0.6% CNT
0.1% CNT COOH

Discussion of Fellowship

Proteins are dependent on four main stimuli:

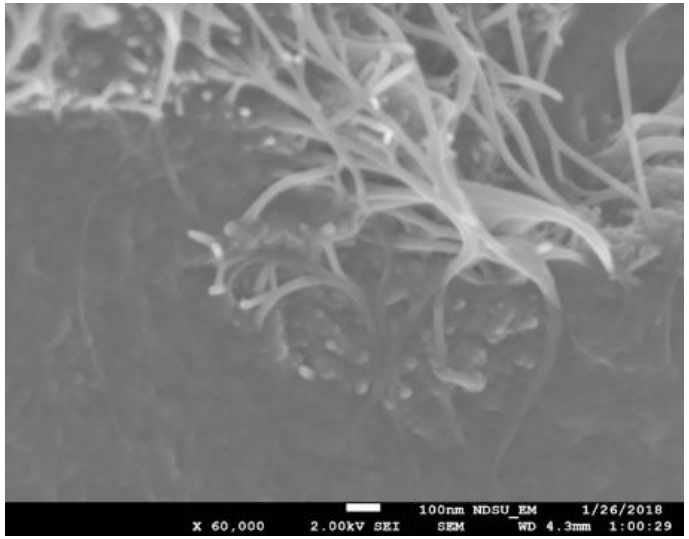
- pH change
- ionic change
- mechanical shear
- hydration

Dispersions of CNT’s were investigated with sonication

CNTNF was compared to CNTC

A new dispersion technique needed to be investigated.

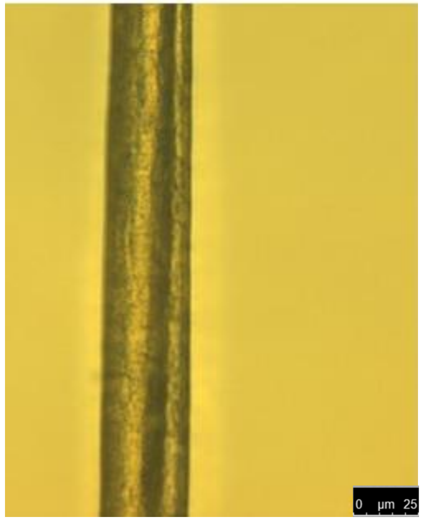
Optimization of CNT percentage needs to be conducted for conductivity



Current Works

	Peak Stress (MPa)		Breaking Strain (%)		Young's Modulus (MPa)	
Homogenized Samples	5000 RPM	10000 RPM	5000 RPM	10000 RPM	5000 RPM	10000 RPM
Neat Films	2.04 ± 0.07	2.17 ± 0.084	95.40 ± 5.64	74.44 ± 8.39	14.06 ± 0.19	12.68 ± 0.44
CNTNF	1.38 ± 0.12	1.84 ± 0.17	23.14 ± 3.41	56.51 ± 10.78	16.71 ± 1.47	17.46 ± 3.70
CNTC	2.28 ± 0.11	2.38 ± 0.20	93.13 ± 7.27	68.08 ± 6.42	12.15 ± 0.66	32.25 ± 10.57

Neat Fiber



Carbon Nanotubes Non-Functionalized (CNTNF)

Carbon Nanotubes Functionalized COOH (CNTC)

	Peak Stress (MPa)	Breaking Strain (%)	Young's Modulus (MPa)
Neat Fibers	12.97 ± 6.18	0.004 ± 0.001	3801.9 ± 366.9
CNTNF Fibers	11.46 ± 3.26	0.009 ± 0.002	1634.7 ± 464.4
CNTC Fibers	20.24 ± 3.61	0.01 ± 0.002	2562.6 ± 506.1

References

[1] F. L. Markley and J. L. Crassidis, *Fundamentals of Spacecraft Attitude Determination and Control.* New York, NY: Springer New York, 2014.

[2] A. Rising and J. Johansson, “Toward spinning artificial spider silk,” *Nat. Chem. Biol.*, vol. 11, no. 5, pp. 309–315, Apr. 2015.

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[5] B. Hoffmann, C. Gruat-Henry, P. Mulinti, L. Jiang, B. D. Brooks, and A. E. Brooks, “Using hydrodynamic focusing to predictably alter the diameter of synthetic silk fibers,” *PLOS ONE*, vol. 13, no. 4, p. e0195522, Apr. 2018.

[6] S. Sampath and J. L. Yarger, “Structural hysteresis in dragline spider silks induced by supercontraction: an X-ray fiber micro-diffraction study,” *RSC Adv.*, vol. 5, no. 2, pp. 1462–1473, Dec. 2014.

[7] M. Elices, G. R. Plaza, J. Pérez-Rigueiro, and G. V. Guinea, “The hidden link between supercontraction and mechanical behavior of spider silks,” *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 4, no. 5, pp. 658–669, Jul. 2011.

[8] F. Zhang, X. You, H. Dou, Z. Liu, B. Zuo, and X. Zhang, “Facile fabrication of robust silk nanofibril films via direct dissolution of silk in CaCl2-formic acid solution,” *ACS Appl Mater Interfaces*, vol. 7, no. 5, pp. 3352–3361, Feb. 2015.

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NDSU

NORTH DAKOTA SPACE GRANT CONSORTIUM

Thank You!

Questions?