Compression/Recovery of Goose Down (Part I) - Experimental

By

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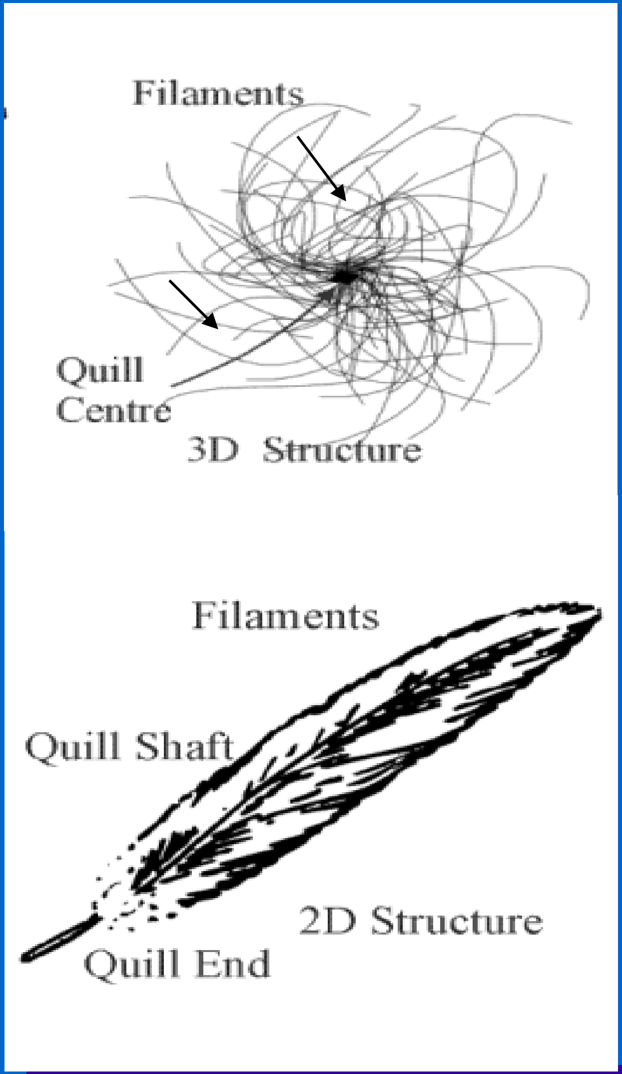
Objective

- To understand the compression/recovery behavior of goose down
- To provide design inputs for compression structures using synthetic fibers
- Develop experimental strategy for handling down

Outline

- Problem Definition
- Background Information
- Goose Down Morphology
- Proposed Model
- Results
- Conclusions

Background on Goose Down

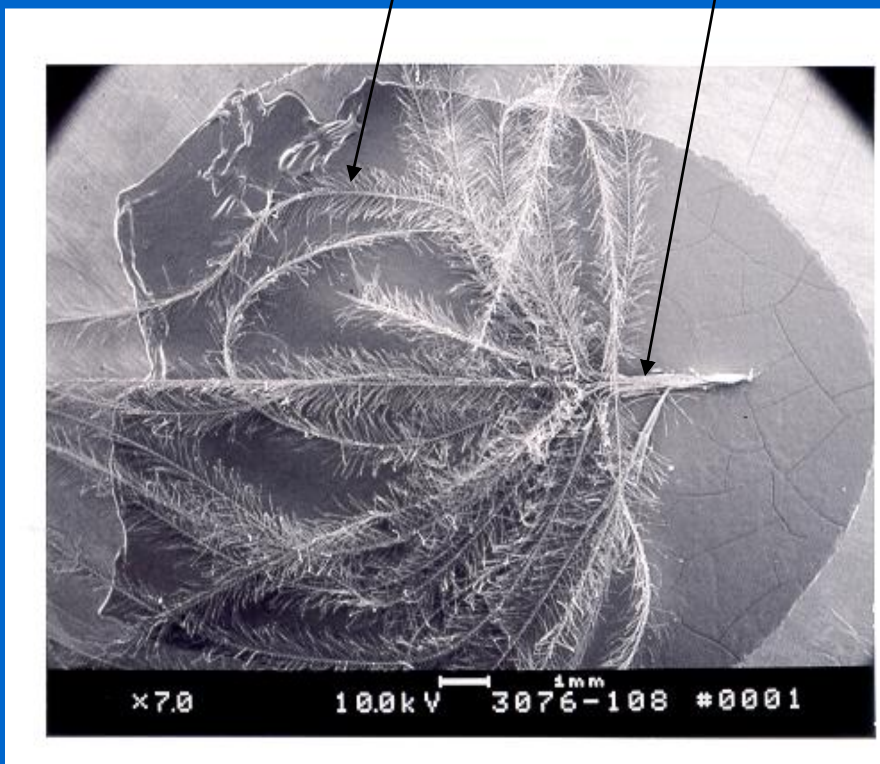


- Down is formed next to the goose skin under the outer feather layer.
- Down feathers are of 3-D structure. They have a core/root but no quill shaft.
- Each down cluster is a spherical plumage of soft filaments radiating in all directions from the stem.
- Feathers are flat, almost 2-D structure. They have a hard, tubular quill shaft.

Down and Half Feather

filament

quill point

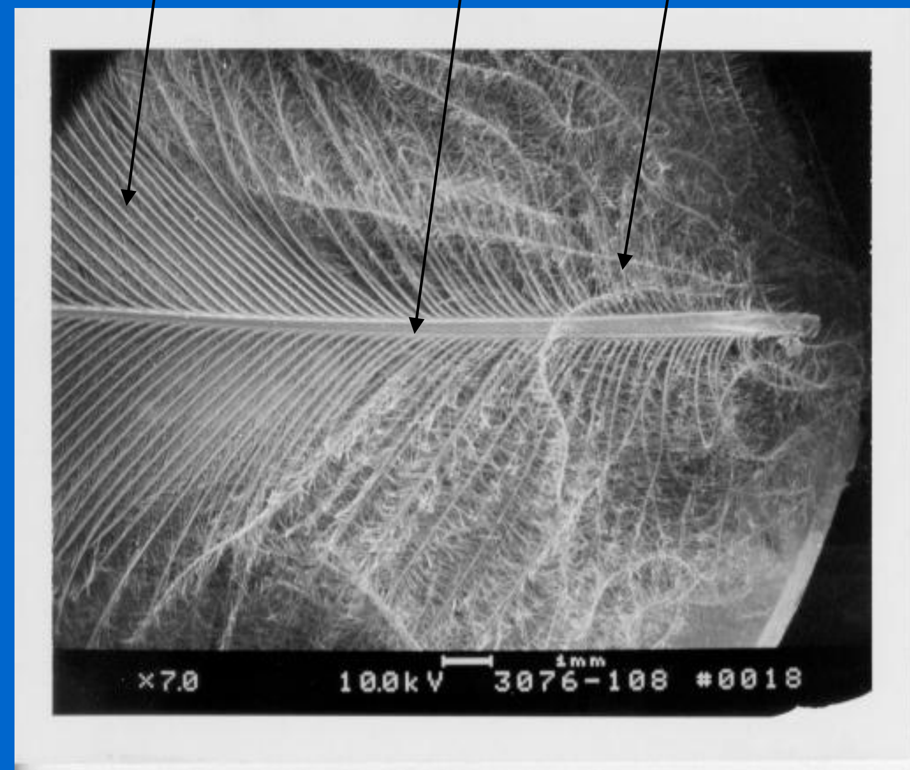


Down Feather

hard filaments

quill shaft

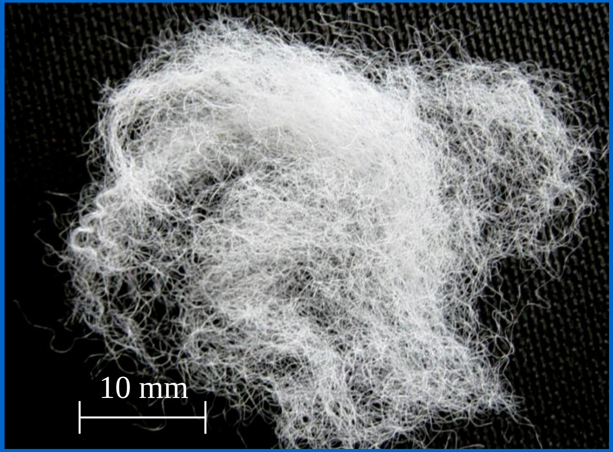
soft filaments



Half Feather

Problem Definition

- Random fiber assemblies can be associated with several important products in the textile industry.
  - Felts / Flooring Systems
  - Compression (Cushion / Pillows)
  - Insulation (Jackets)
  - Fill Materials
    - Natural: Wool, Cotton, Down
    - Synthetics Fibers

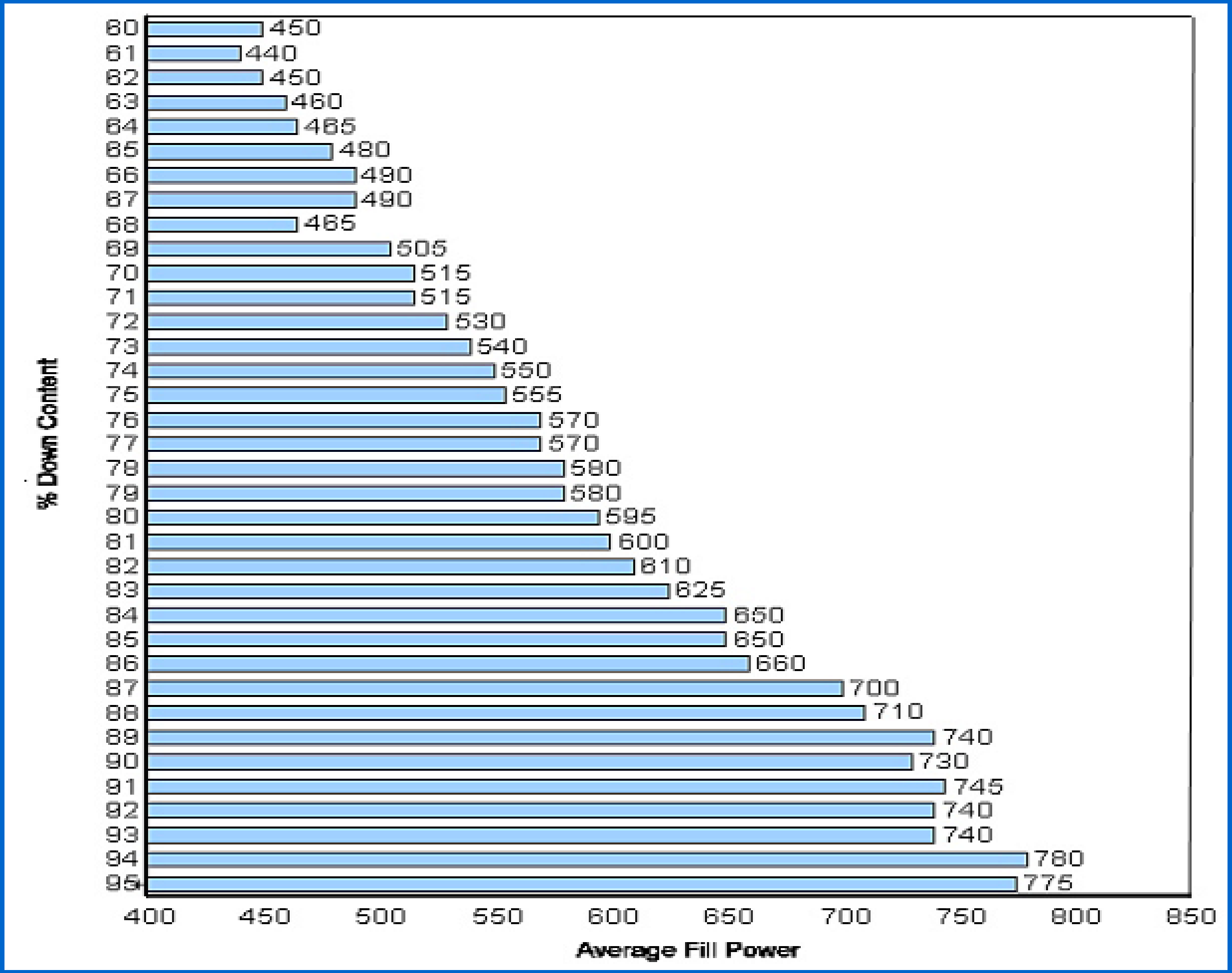


- Product value is highly dependent on the materials response to repeated loading for compression applications or insulation value for warmth.
- Goose down is among the best, but little work has been done to model its behavior or understand the underlying mechanisms that influence its behavior.

Fill Power

- The quality of down is determined by "fill-power"
- It is the space occupied (in^3) by 1 ounce of down.
- The fill-power is controlled by blending the half-feathers into it.
- It also depends on the size of the down plumage

Relationship Between Fill Power and Down Content

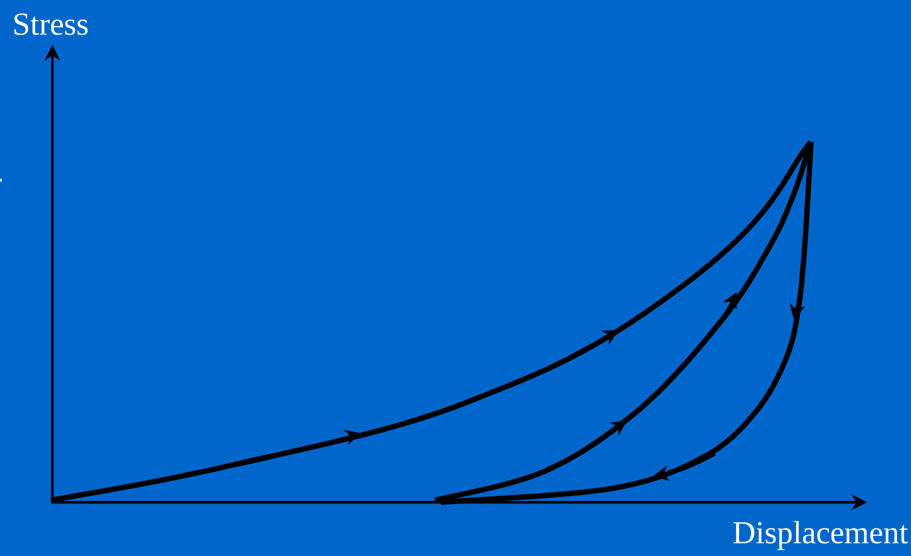


Contaminants

- Dirt
- Broken and whole feathers
- Down fiber segments
- Residue

Common Behavior of Fiber Assemblies

- **A representative loading, unloading, and re-loading curve for a loose fiber material in a piston-cylinder device.**
  - **Hysteresis**
  - **Irreversible deformation**
  - **Maintained peak stress**



Previous Works

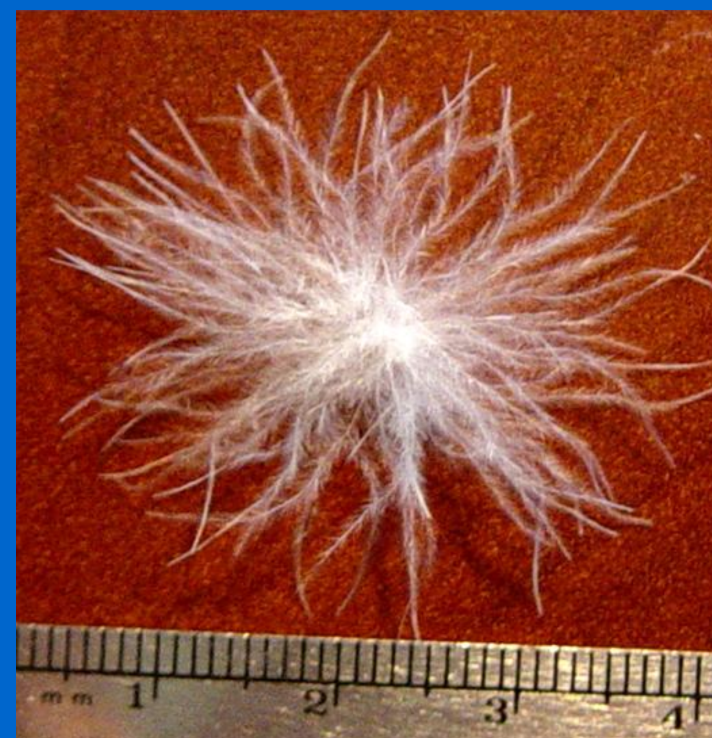
- **Developed mainly for wool fiber networks (Komori *et al.* 1991, Carnaby *et al.* 1989)**
- **Focus on beam bending as the primary source of elastic strain-energy.**
- **Relate bulk stiffness to individual fiber bending and orientation.**
- **These approaches are very complicated and difficult to implement and have exhibited only limited success.**
- **Limited applicability to goose down due to the inherent differences in structure.**
- **KEYS: Fiber bending, slippage, orientation.**

Modified Mullen's Model

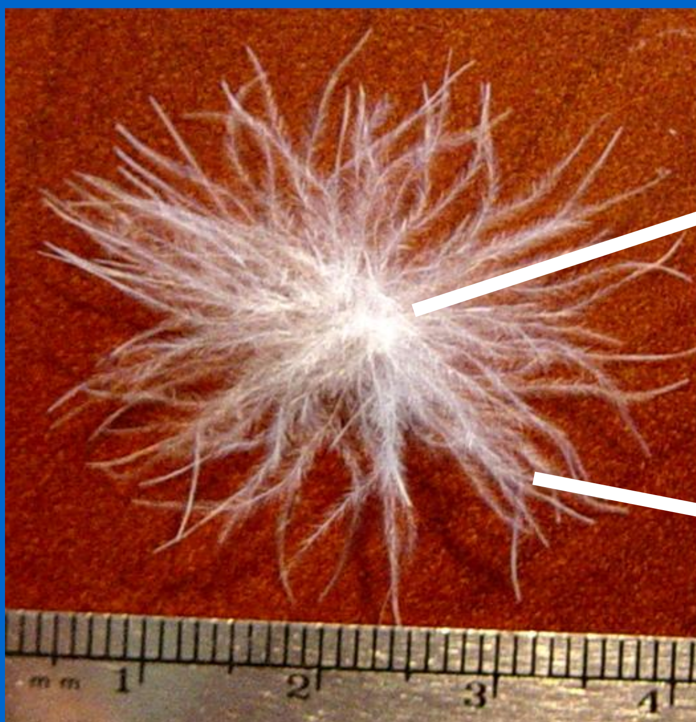
- **Use hyperelastic theory to determine the stress in the system based from the strain energy density.**
- **Primary Orientation**
  - **The majority of the irreversibility results in a change in overall orientation of the primary structures. They will tend to orient away from the loading direction.**
- **Tertiary Contacts**
  - **Significant contacts occur between tertiary structures resulting in elastic deformation of the secondary structures.**
- **Contact Energy Distribution**
  - **The contact energy will be assumed to follow a distribution rather than being constant throughout deformation.**

Goose Down Morphology

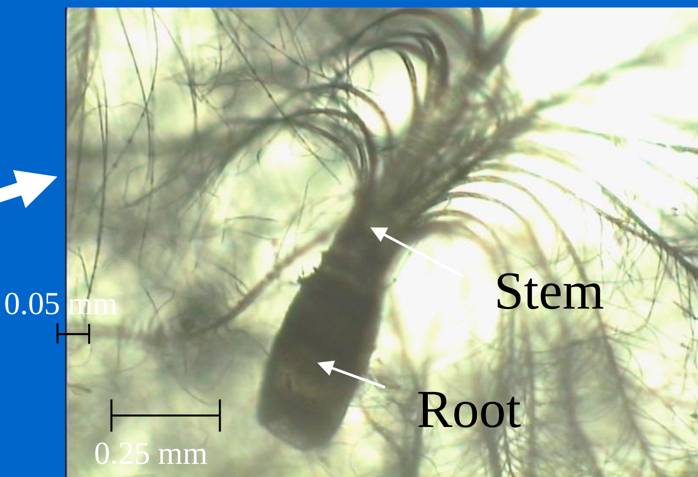
- **The main component within a sample of goose down is the *cluster*.**

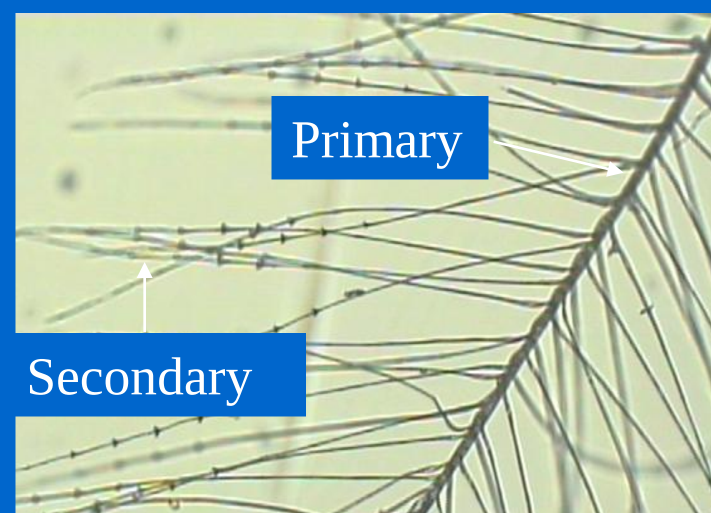


Components of a Goose Down Cluster



Single Cluster



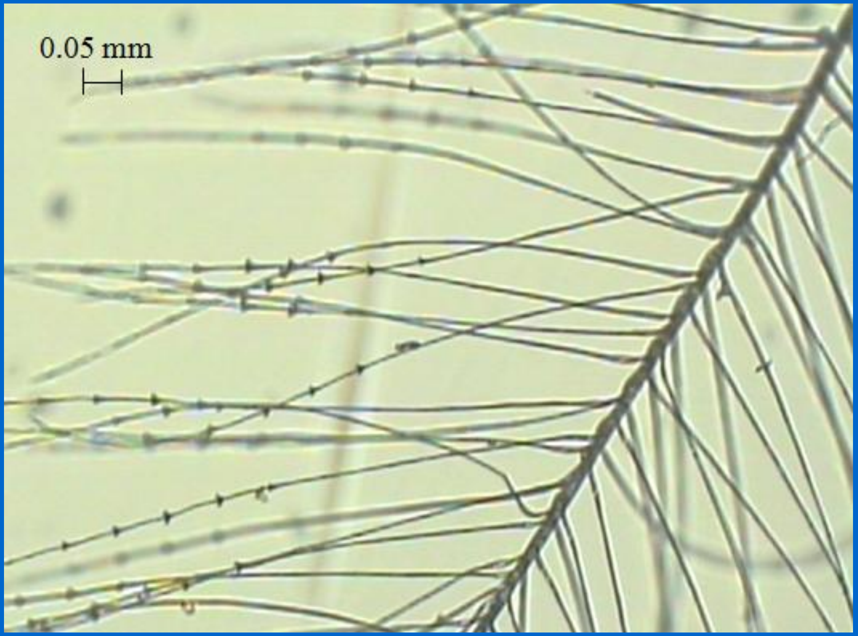


Critical Dimensions

- Clusters
  - Diameter: 5mm to 70 mm
- Primary Structure
  - Length: 5mm to 33 mm (Avg: 20 mm)
- Secondary Structure
  - Length: 0.35 mm to 1.4 mm (Avg: 0.65 mm)
  - Spacing: 0.06 mm

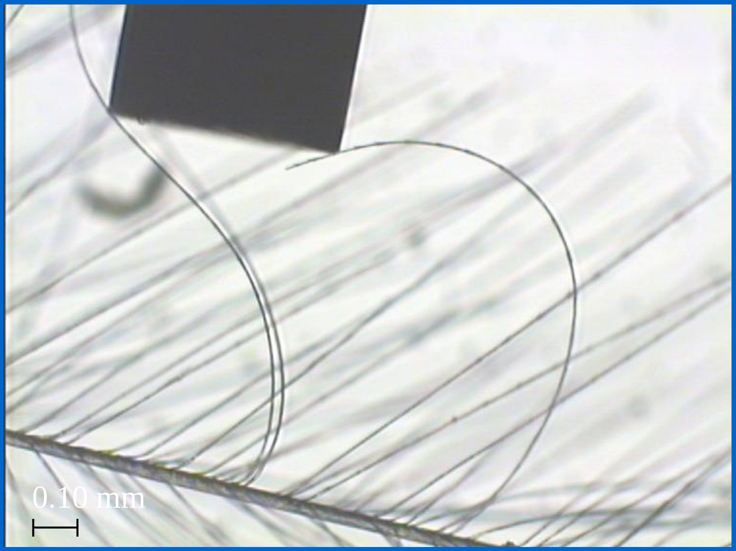
Primary Structures

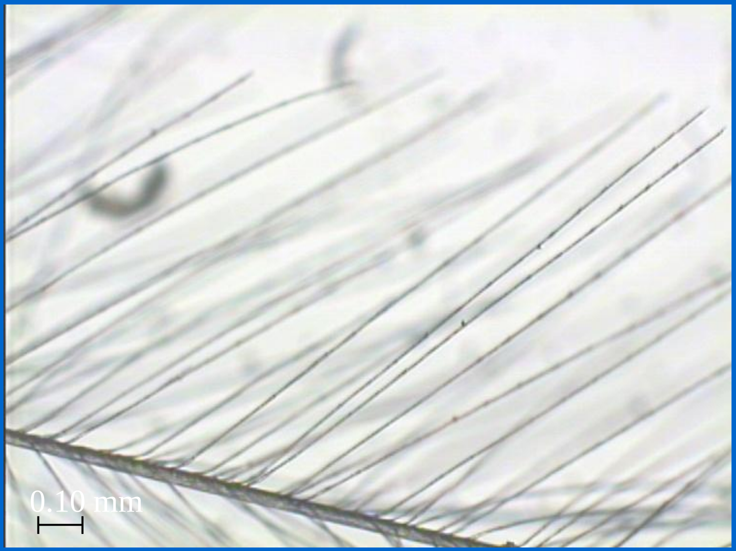
- Beta – Keratin is material of composition
- Modulus 1.3 - 2.3 GPa
- Limp and can barely support own weight



Highly Elastic Secondary Structures

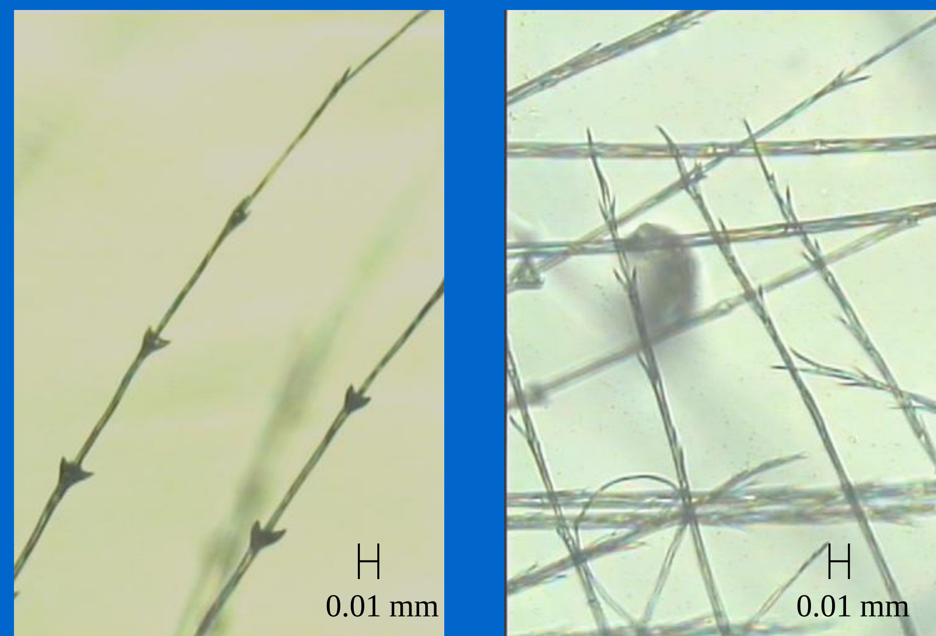
- **Secondary structures are highly elastic and fully recover from large deflections.**
- **Significant source of stored elastic strain-energy.**





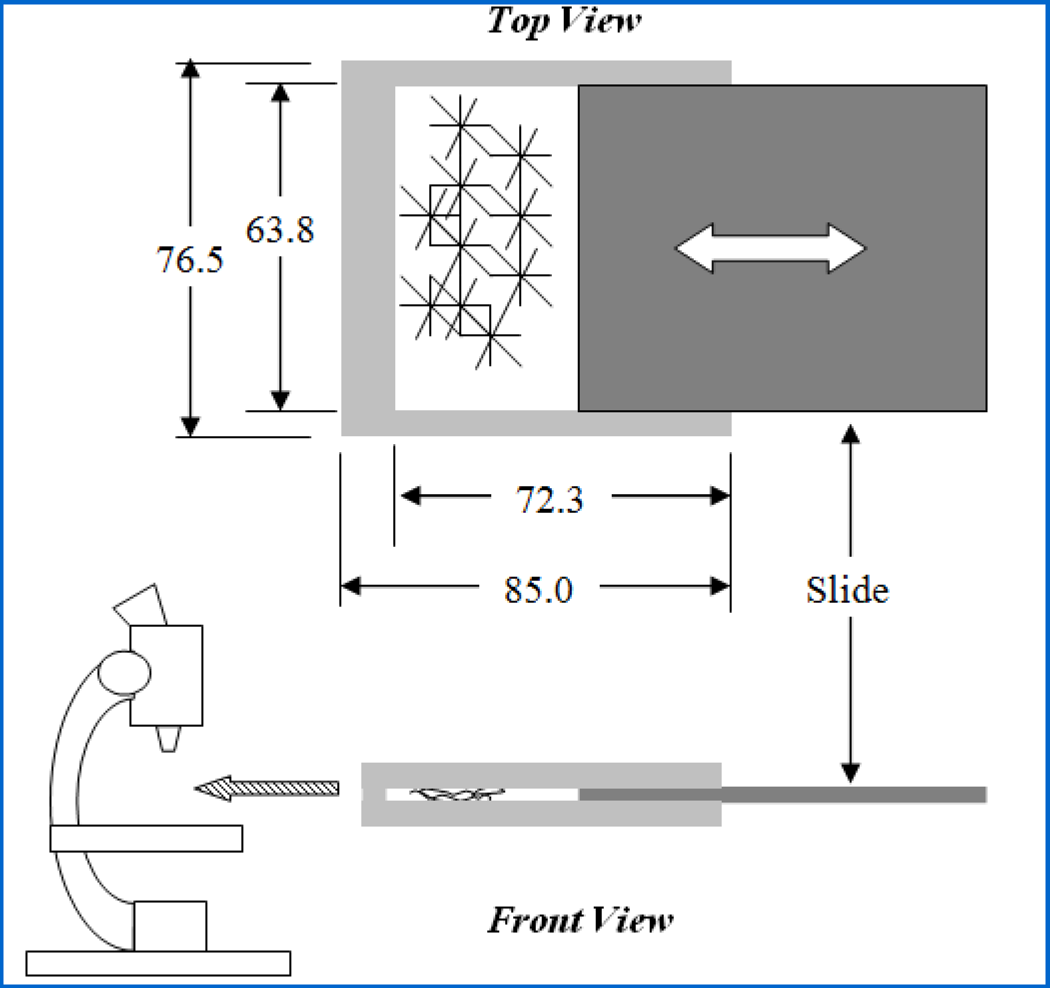
Tertiary Structures

- **A small tertiary structure is present the secondary branches.**
- **The tertiary comes in two forms:**
  - **Solid “Heart” Shape**
  - **Split Shape**
- **Prevent slippage in one direction.**
- **Induce secondary bending when they come into contact with an applied load.**

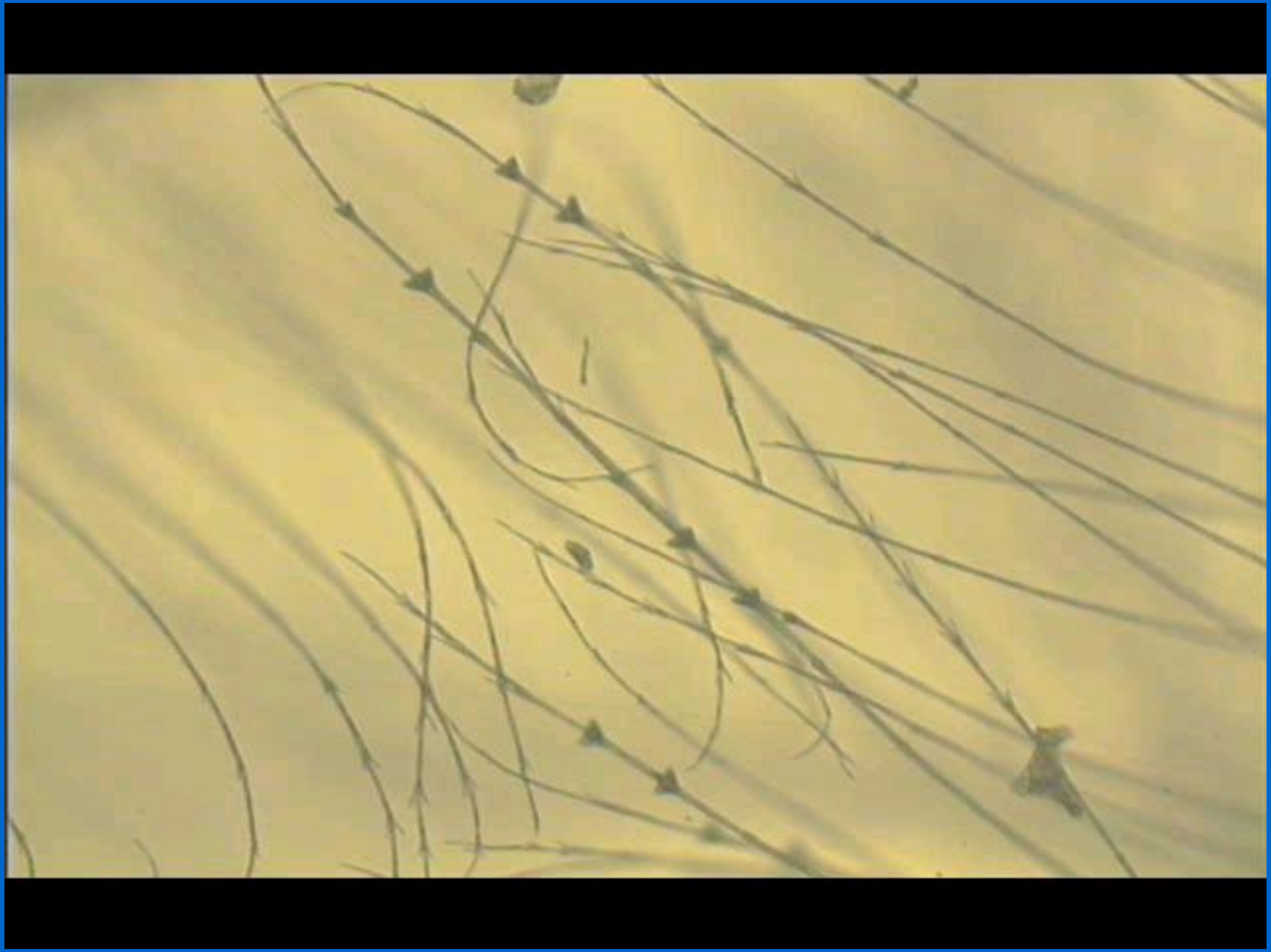


Solid Tertiary (Left) and Split Tertiary (Right)

Schematic of Test Setup for Dynamic Studies



Video



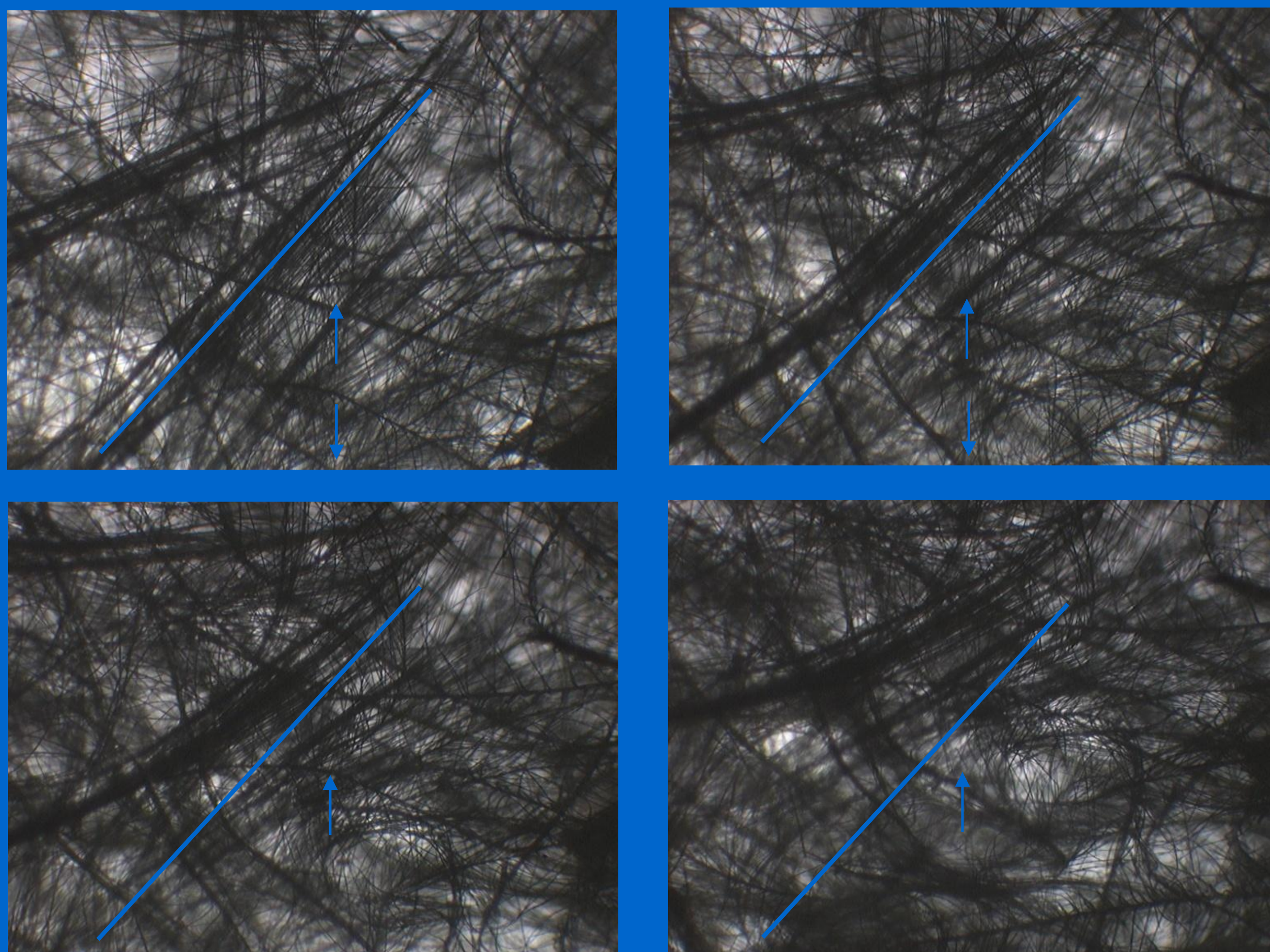
Observations of Dynamic Studies

- Generally, two secondary structures slide freely past each other until two tertiary meet for bending to commence
- Tertiary structures cause a single secondary to bend in multiple locations and store more elastic energy
- Tertiary structures prevent secondary from slipping and experience even greater bending
- Tertiary-to-tertiary unions will slip past each other (unhooking) once a certain degree of relative displacement between primary structures has occurred

Observations of Dynamic Studies-Cont.

- At lower densities, more relative translation occurs
- With increased compression, increasing number of secondary's remain bent due to fewer tertiary-to-tertiary engagement slipping /unhooking
- The stored elastic energy in the deformed secondary's is significant and responsible for recovery
- The inability of secondary structure to slip results in re-orientation of primary structures perpendicular to the loading direction

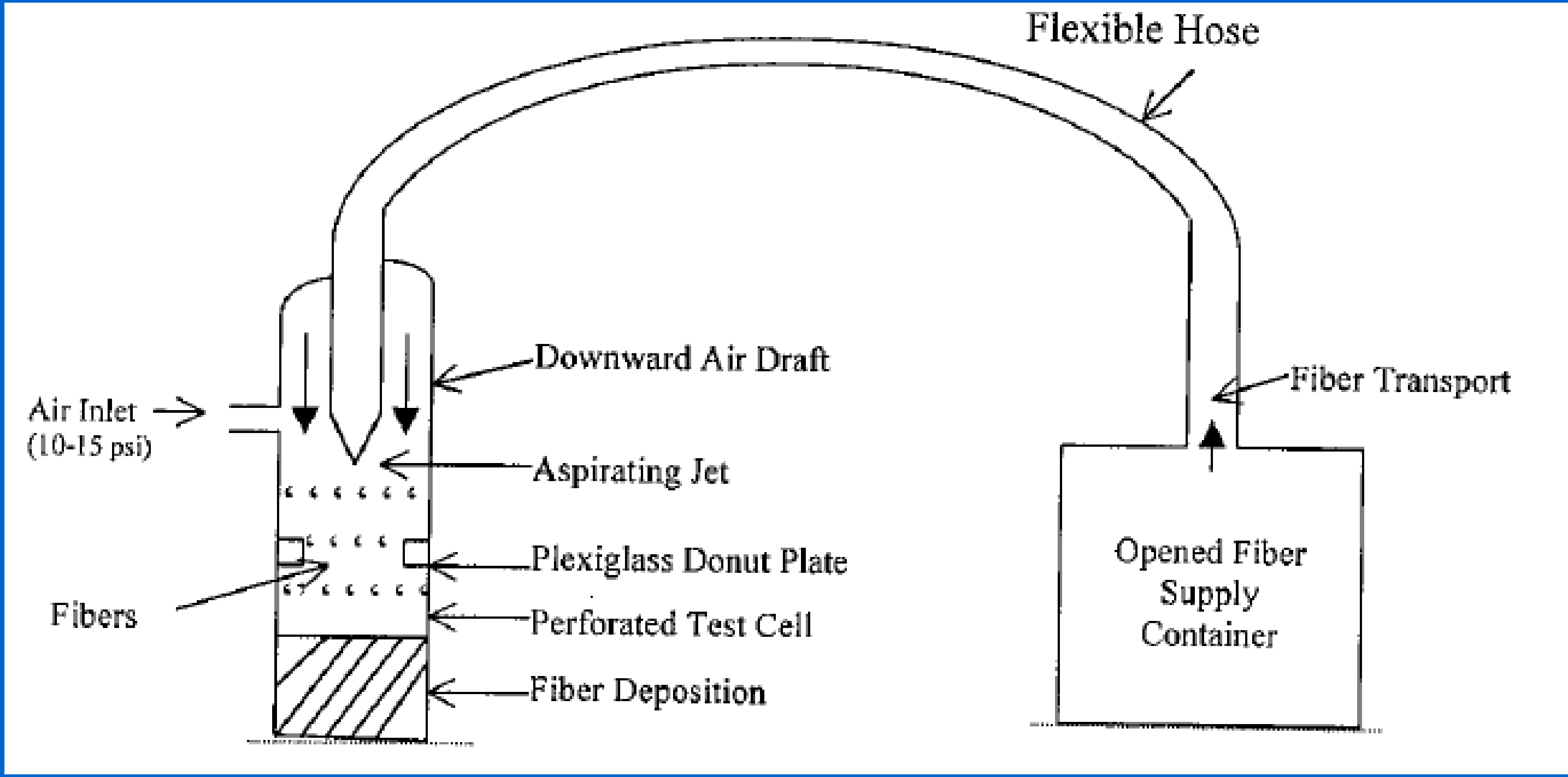
Orientation Change in Goose Down



Experimental Set-up

- Down is loaded into a metallic container with small holes on it
- The piston compresses the feather and reverses at same strain rate
- There is a 5-minutes recovery period before it is compressed again
- Each sample will be compressed 5 times

Schematic of Fiber Loading in Test Cell



Independent Variables

Four independent variables will be studied:

1. **Types of down (with different fill-power)**

2. **Density**

3. **Percent compression**

4. **Compression speed (strain rate)**

Independent Variable (con't)

Types of down:

	Down Property		Mean Tensile Property of 10 Filaments			
Product ID	Grade	Fill Power in^3/ounce	dpf (denier)	Modulus (GPD)	Tenacity (GPD)	Elongation %
WGD 800	excellent	800	3.76	20.78	1	8.14
WGD 750	excellent	750	3.25	19.09	0.87	9.79
WGD 600	better	600	4.78	14.98	0.83	8.99
WGD 500	good	500	4.78	13.36	0.69	6.7

	down	wool	silk	cotton
dpf	3-5	4-5	1	1.5-2
tenacity	0.5-1	1-2	3-5	2-3

Independent Variable (con’t)

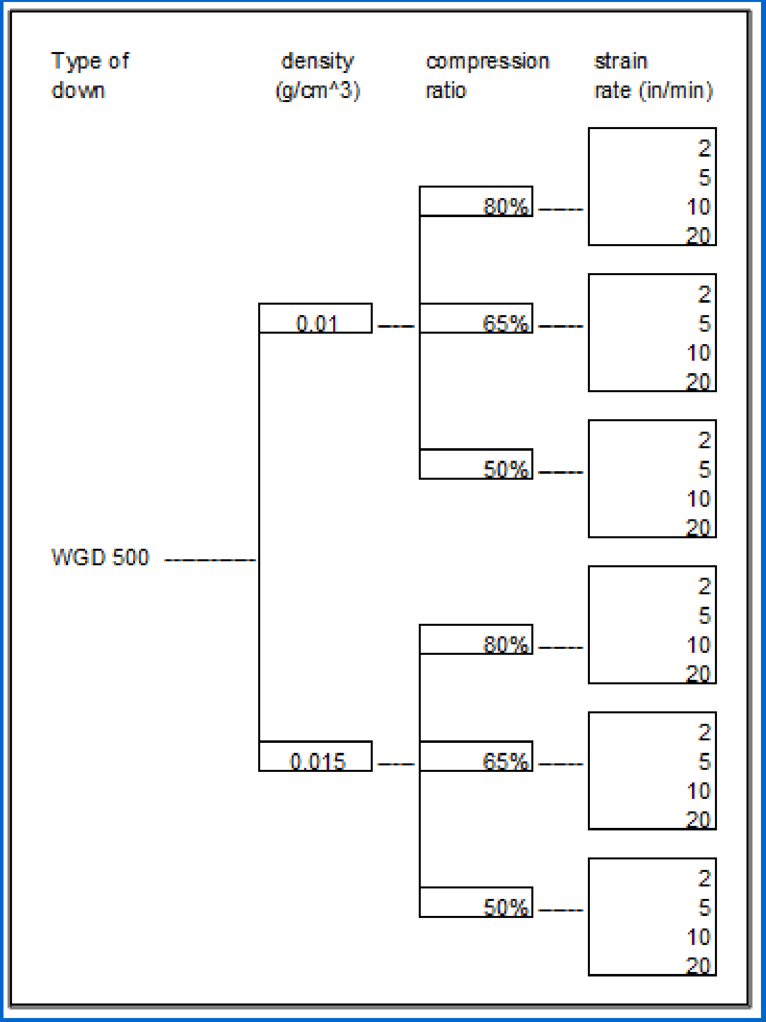
Bulk Density:

- **Density of 0.01 and 0.015 g/cm^3 are tested.**
- **These are the lower and upper bound found in the down pillows in the market.**

Strain rate:

- **Strain rate of 2, 5, 10 and 20 in/min are tested**
- **This tells us the effect of the speed when someone lies down on the pillow**

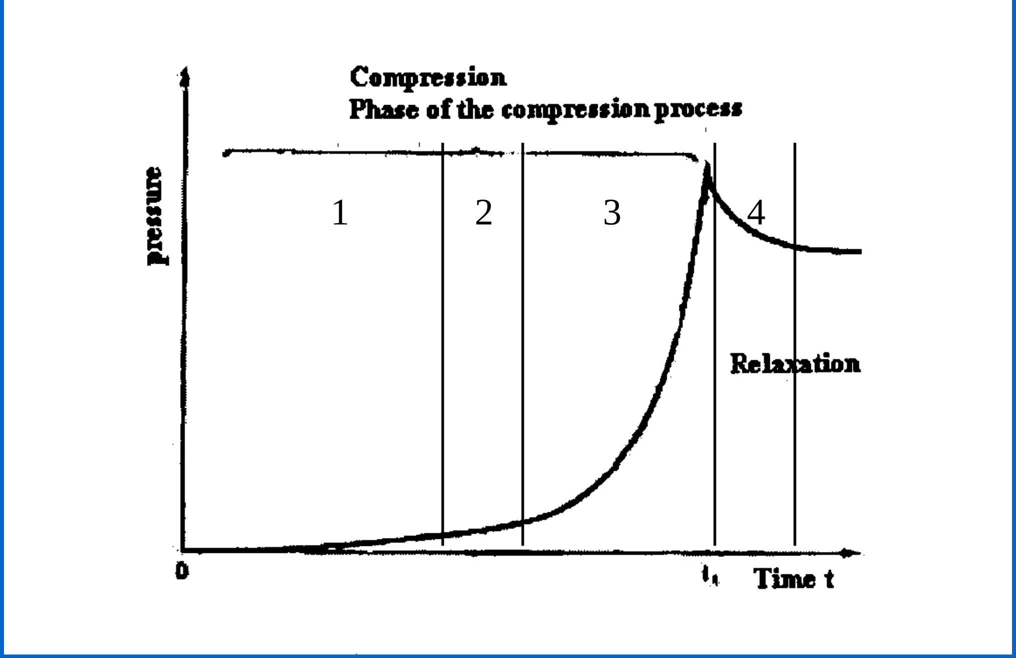
Schematic of Experiments of Each Type of Down



Independent Variable (con't)

Percent Compression:

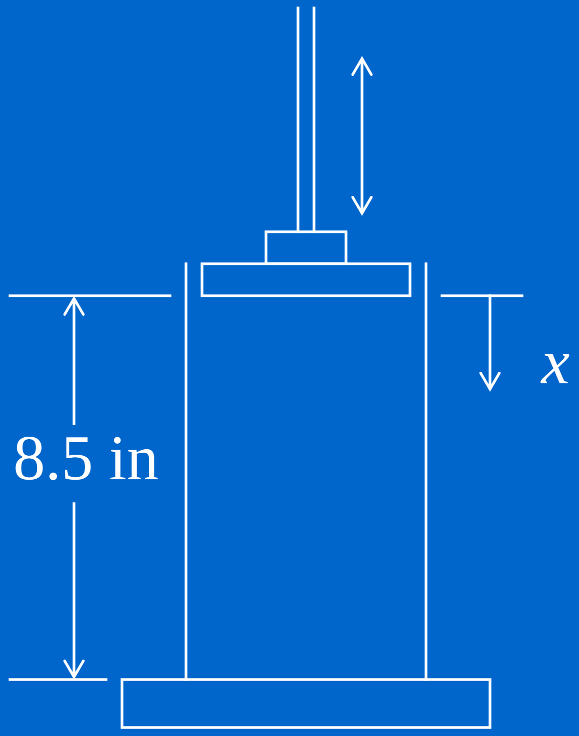
- **The sample will be compressed at 50%, 65% and 80%**
- **This covers all phases of compression**

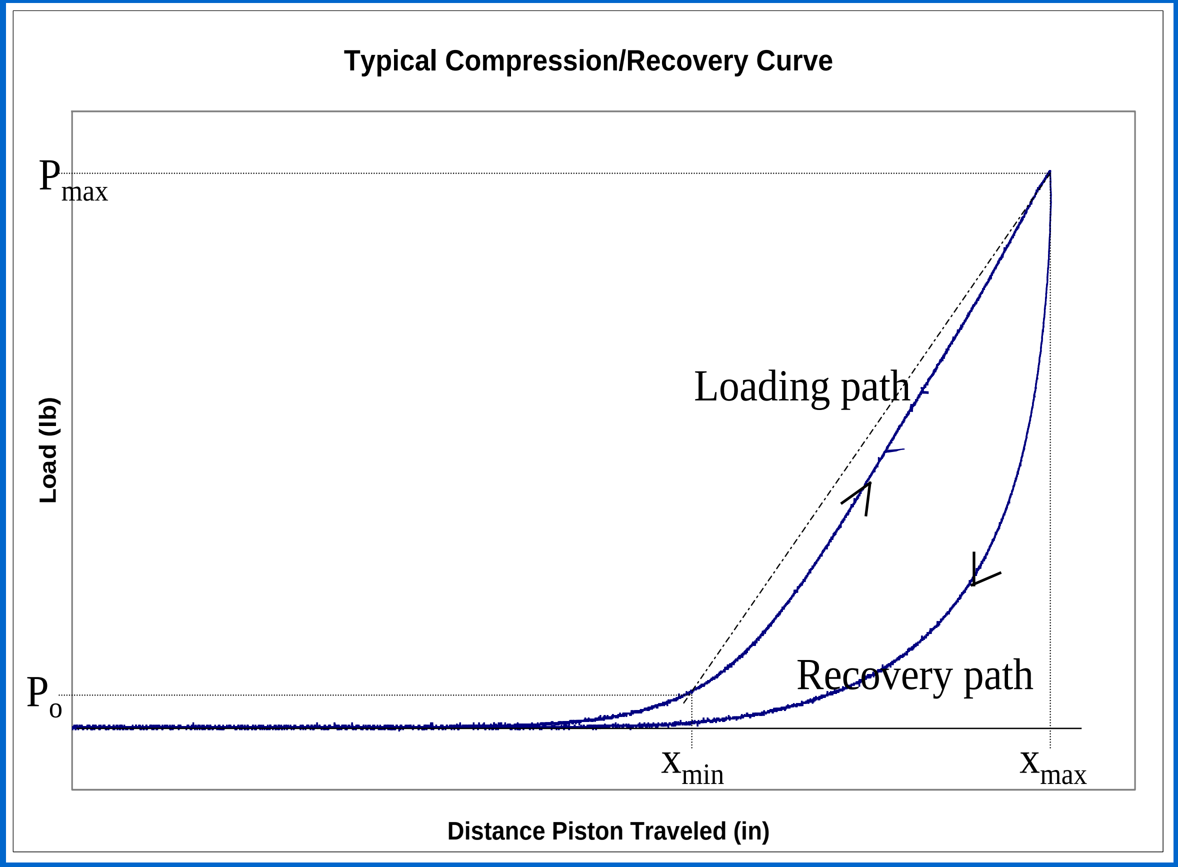


Four phases can be distinguished:

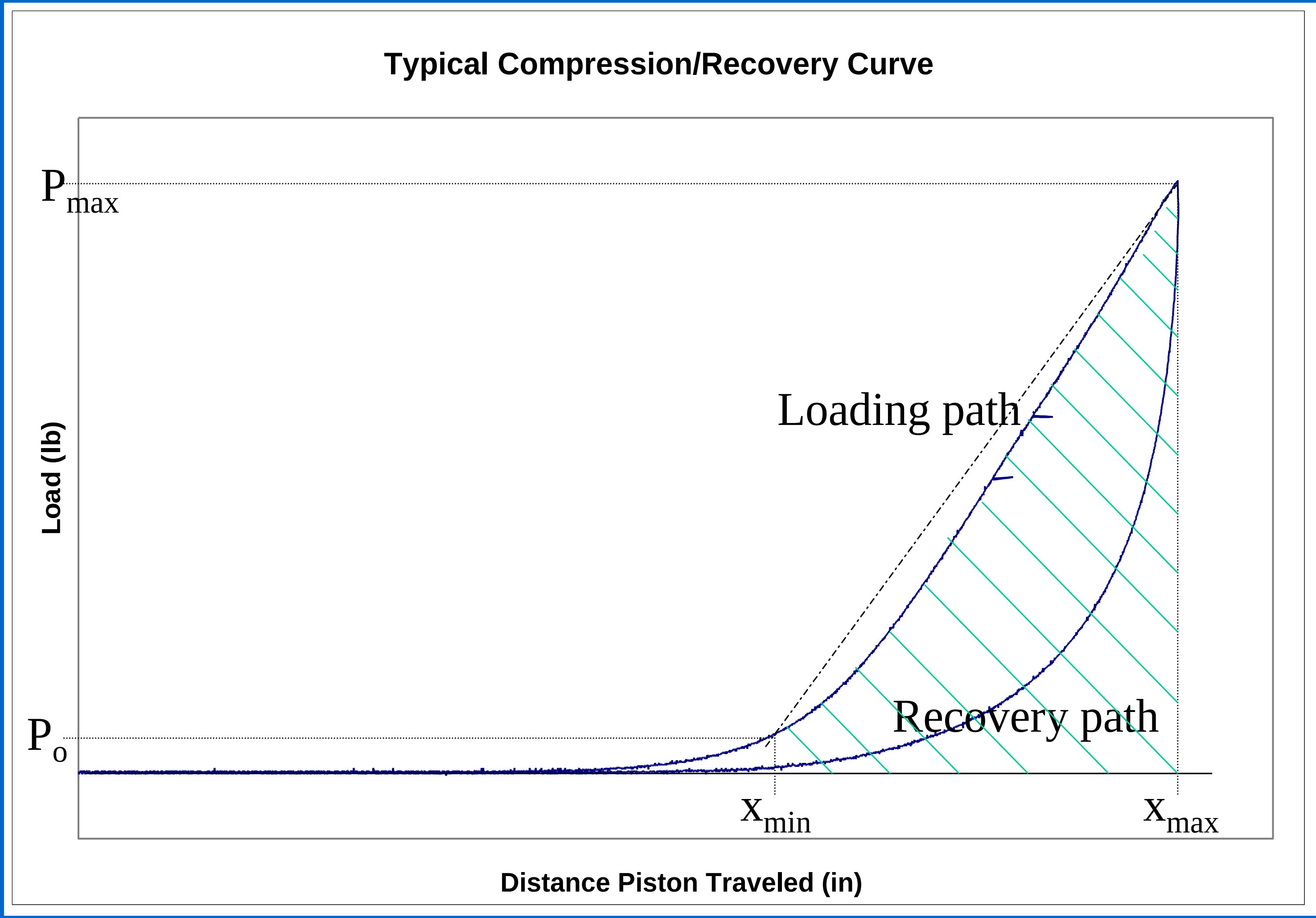
1. **Displacement of fiber layer**
2. **Sliding of fiber**
3. **Bending of fiber**
4. **Pure crushing of fiber**

Typical Compression/Recovery Curve

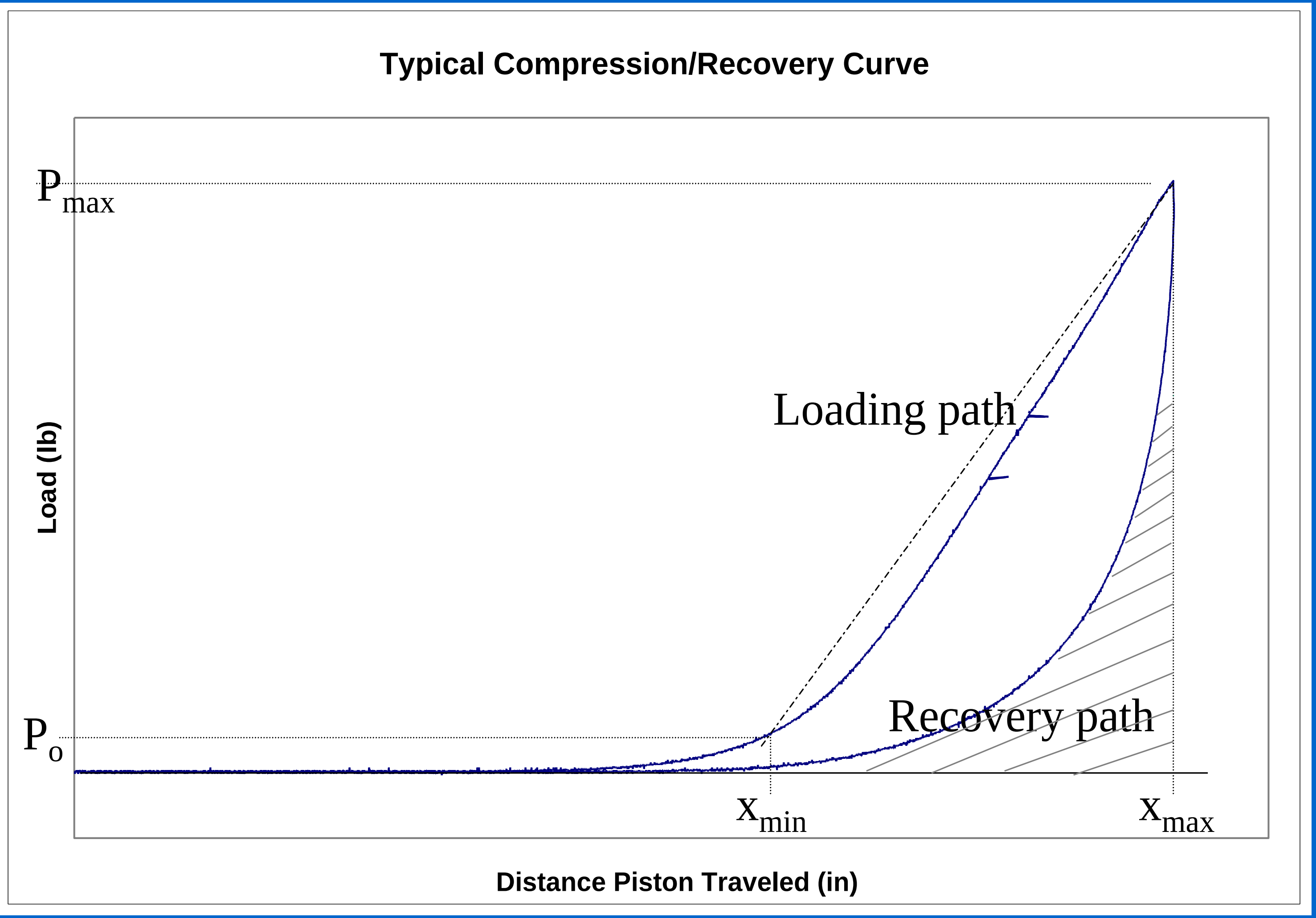




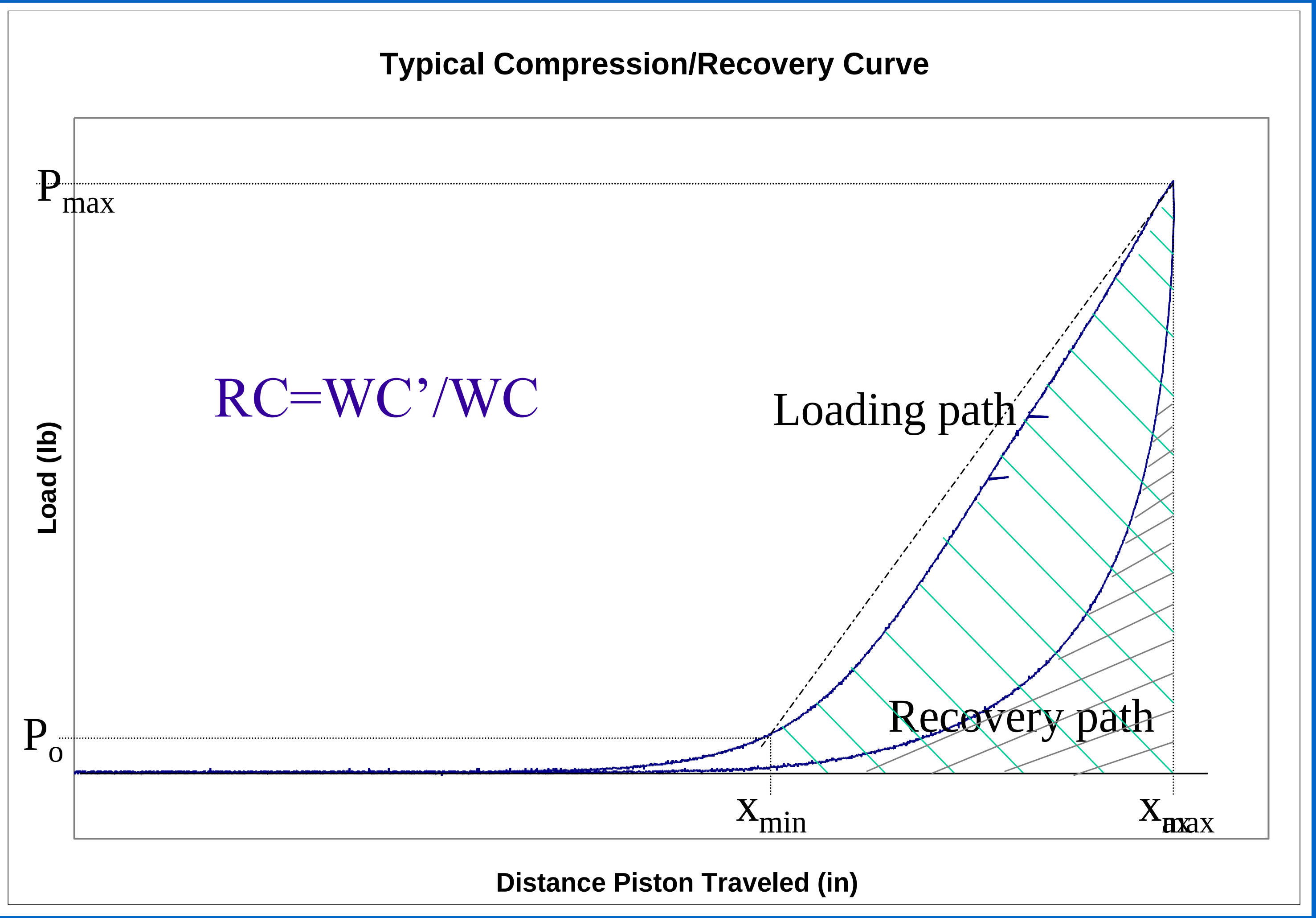
Energy Compression - WC



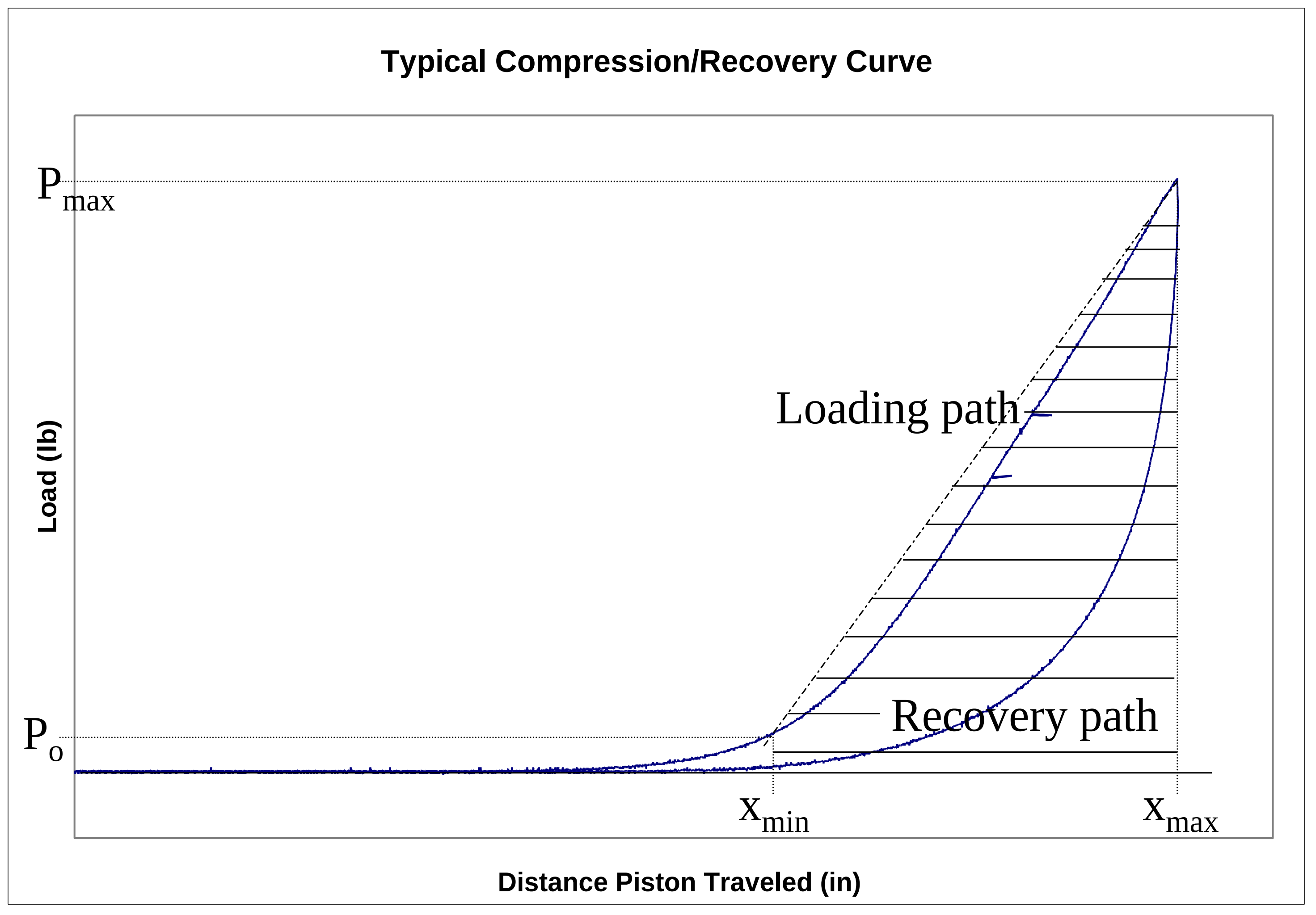
Energy Recovered – WC[1]



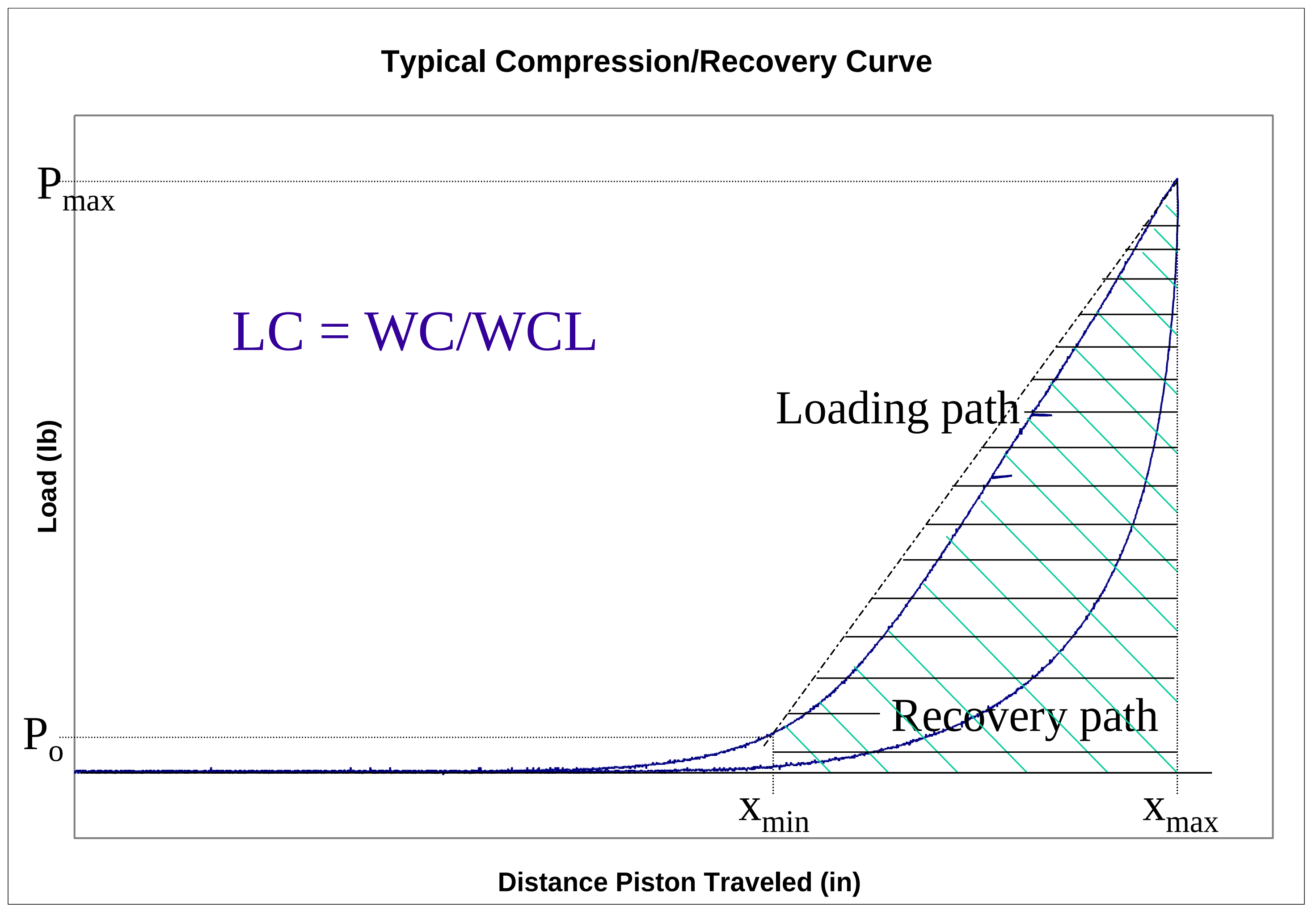
Resilience - RC



Linear Energy - WCL



Linearity - LC



Mathematical Representation

$$WC = \int_{x_{min}}^{x_{max}} P_{loading}\,dx \qquad \text{(lb*in)}$$

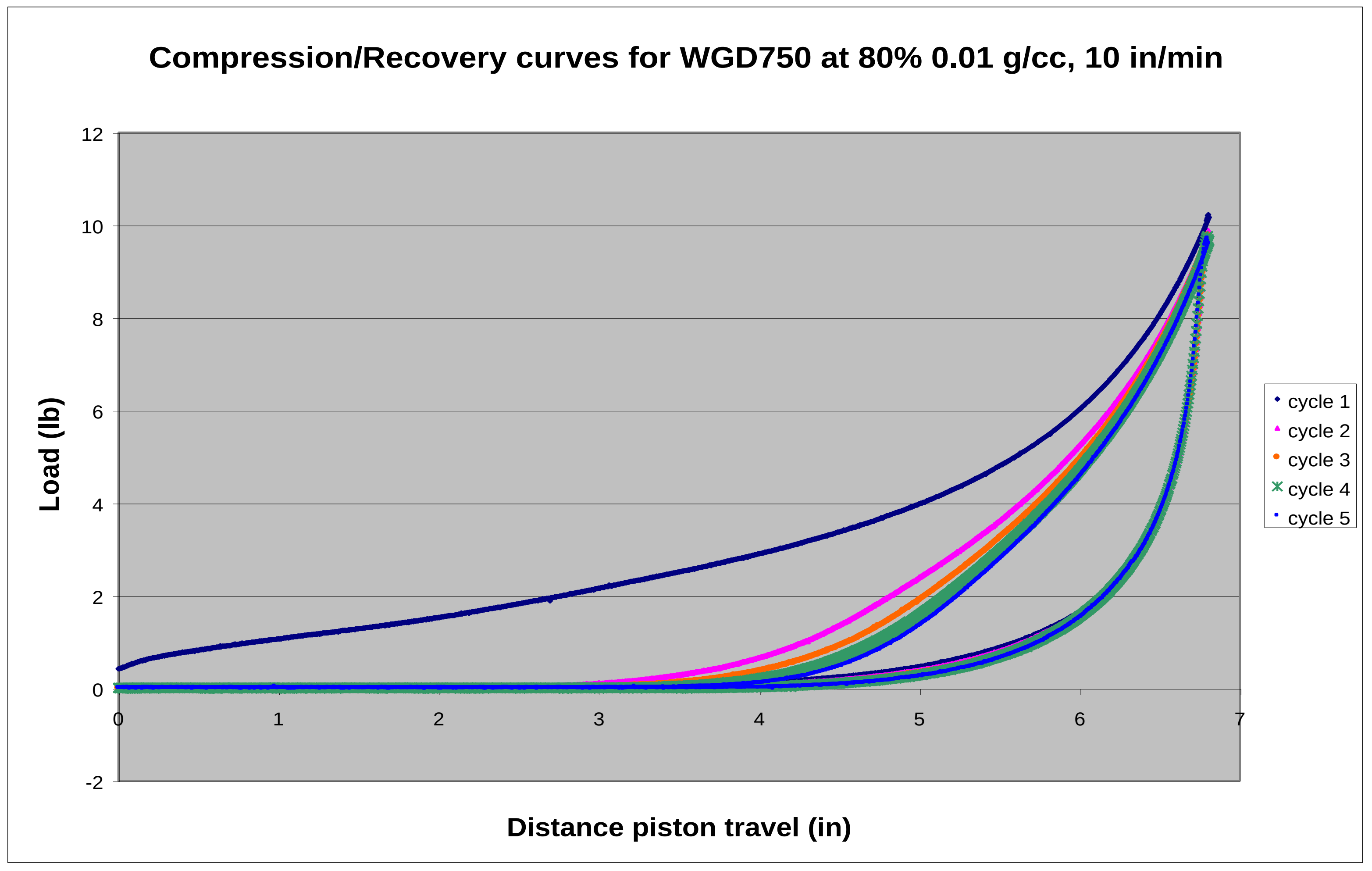
$$WC' = \int_{x_{min}}^{x_{max}} P_{recovery}\,dx \qquad \text{(lb*in)}$$

$$WOC = \int_{x_{min}}^{x_{max}} P_{linear}\,dx \qquad \text{(lb*in)}$$

$$RC = \frac{WC'}{WC} \qquad \text{(no unit)}$$

$$LC = \frac{WC}{WOC} \qquad \text{(no unit)}$$

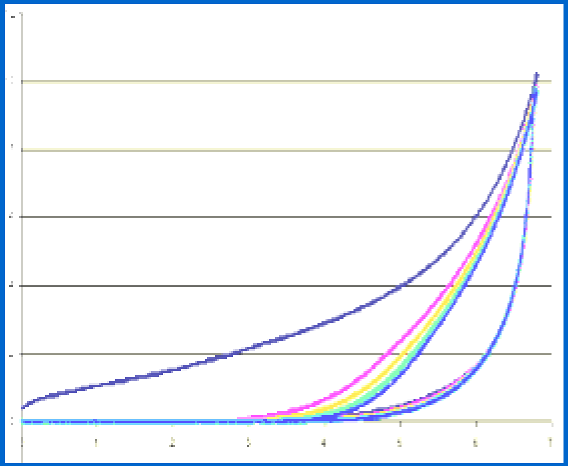
Compression/Recovery Curves of Down



Piston-Cylinder Response

Hysteresis:

- **Due to the tertiary configuration on the secondary structures. They do not physically lock but slip as soon as the load holding them together is removed.**



Irreversible Deformation:

- **Due to permanent reorientation of the primary structures and some pinning caused be tertiary structures.**

Conclusion - Physics of Down Deformation

- Reasons for difference between first and subsequent compression cycles
  - Initially, the primary structures undergo irreversible re-orientation and translational change
  - The degree of change is a function of the initial density
    - Less dense samples have fewer interactions to drive re-orientation

Conclusion - Physics of Down Deformation - Cont

- The hysteresis in loading and unloading paths is due to energy expended in re-orienting & translating the primary structures
- The sharp drop in recovery curve is due to combination of orientation and density effects:
  - The density of tertiary contacts has increased
  - Orientation distribution of primary structures has evolved with resultant stable contacts
  - These phenomena leads to stiffer response

Synthetic Fibers for Comparison

- **Synthetic Fiber Preparation on Rando Blowing System Before Loading (Three Steps):**
  - **Pre-feeding clumped fibers**
  - **Opening of fibers via mechanical cylinder conveyors**
  - **Air transport of fibers (200 lbs/hr) into storage**
- **Three types of Synthetic Fibers Used:**

Type	DPF	CTU	CPI	shape	Polymer
233A	1.65	30	12.8	round	homopolymer
667	6.5	38	4	round	bi-component
118	6	28.5	8.5	round	homopolymer

Next Lecture...

- Evaluate both down and synthetic fibers
- Compute the WC, LC and RC, and compare them with those of down
- Develop models using Neural Network Analysis
- The model should predict P_m, WC, LC, RC and Recovery height
- Provide input to develop new products

Thank you