Development of an MRI-Compatible Dynamic and Deformable Imaging Phantom

Group 29
Members: Jacie Sales, Leah Laux
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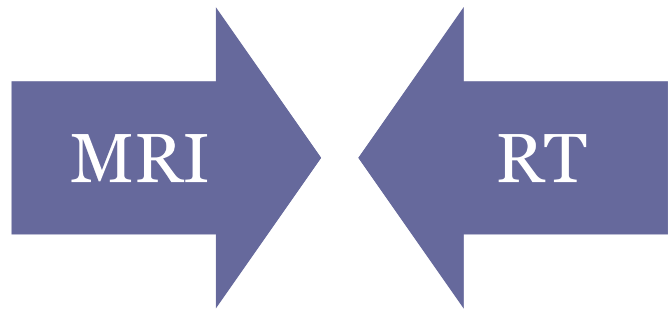
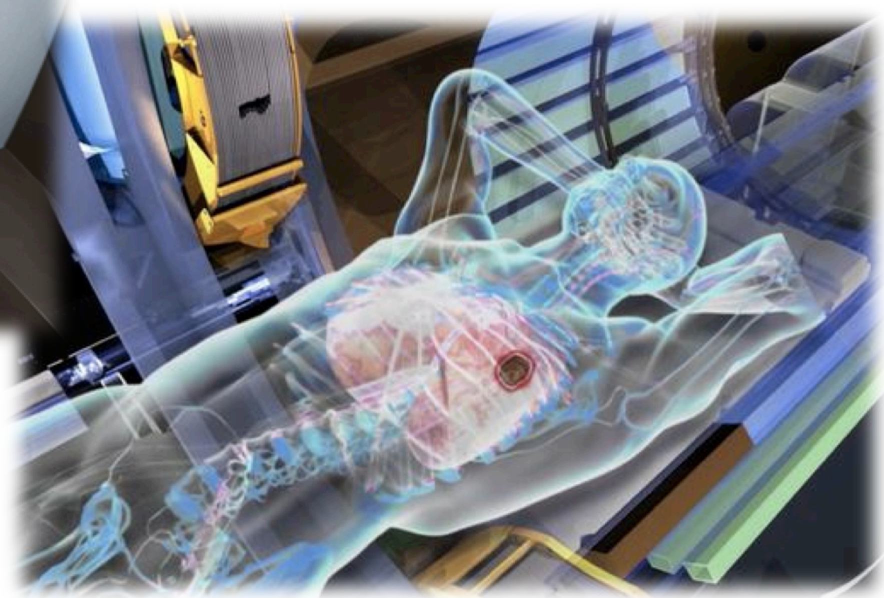
ViewRay System

viewray.com





Project Scope

- Design an imaging phantom that can be used to assess the accuracy of the ViewRay software in calculating the deformation of moving organs in an MRI scanner

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- Capable of:
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  - Deforming in 3 dimensions
  - Rotating in 3 dimensions
- In a Way that is:
  - (Binary) controllable
  - Precisely known
  - Able to operate in an MRI environment
  - Able to be imaged by an MRI

Project Specifications

Translation	Deformation	Rotation	Volume Change
x, y, and z directions	x, y, and z directions	about x, y, and z axes	Known pre and post deformation volumes
5 ± 0.5 cm	2 ± 0.5 cm	± 0.5^{o}	25%

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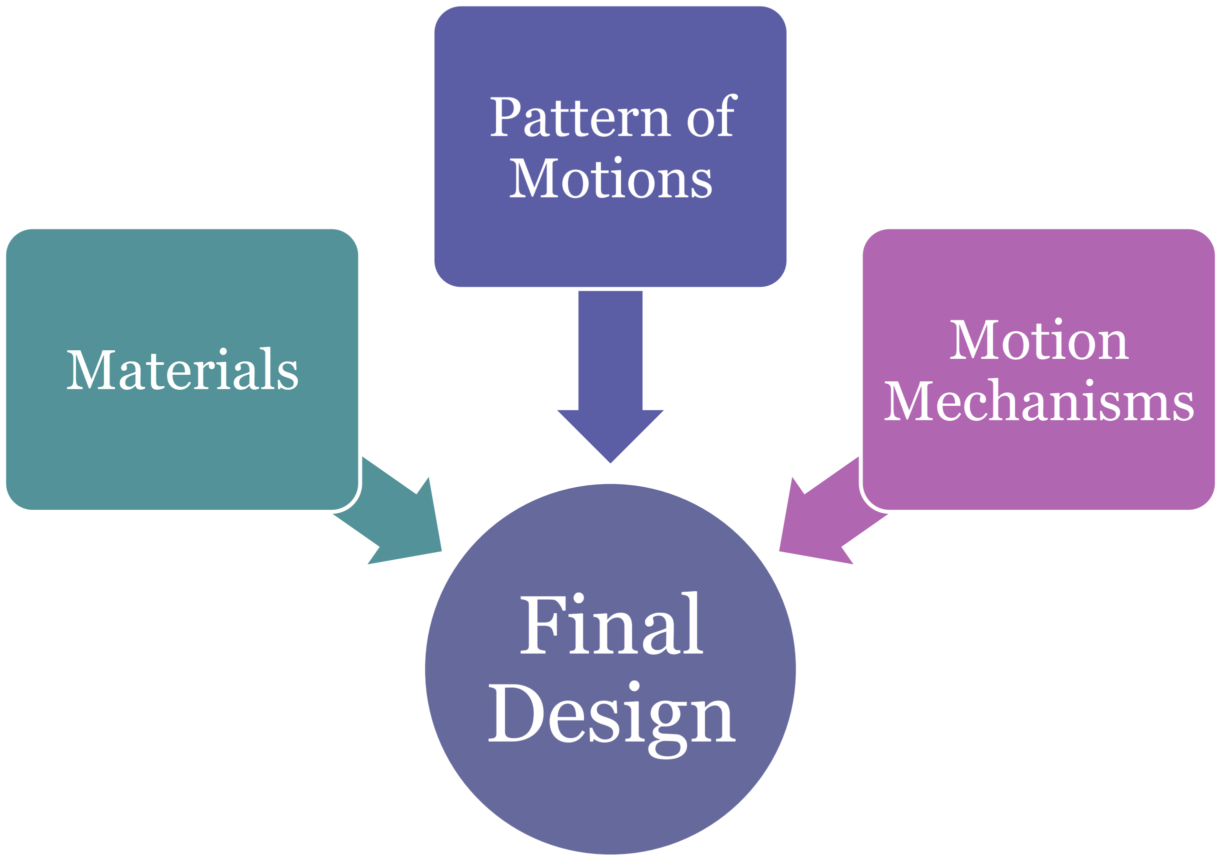
Motion must be:

- Reproducible and stable
- Precisely known
- (Binary controllable)

Physical Characteristics:

- Weight ≤ 150 lbs
- Dimensions: ≤ 50x30x50 cm
- Maximum price: $10,000 – $30,000

Plan of Action



Materials

- MRI Compatible
  - No metals
- MR Imageable
  - Tissue-like relaxation times
  - T_1 – time to become magnetized in magnetic field
    - Thermal interactions
  - T_2 – length of transverse magnetization in a perfectly uniform magnetic field
    - Static internal fields

Materials

- **Gels**
  - Pure
  - Paramagnetic Doped
- **Semi-Solids**
  - Inflatable Balloon
  - Foam
  - Biological Tissue
- **Liquids**
  - Aqueous Solutions
  - Non-aqueous Solutions

Gels

- Agarose
- Gelatin
- Zerdine
- Polyvinyl Alcohol Cryogel (PVA-C)
- Silicone
- Soft Polyvinyl Cholride (PVC) / Plastisol
- Carrageenan gel
- Polyacrylamide

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* paramagnetic ions

Pugh Chart *Imageable Materials*			Pure Gels								Paramagnetic Doped Gels				Non-gel Materials		
		Weight	Agarose	Gelatin	Zerdine	PVA-C	Silicone	Soft PVC	Carrageenan	Polyacrylamide	Agarose – Copper	Agarose - Nickel	PVC – Nickel Chloride	CAG	Balloon	Foam	Biological Tissue
Deformation	Consistent	8	8	8	8	8	8	8	8	8	8	8	8	8	4	4	6
	Force	10	6	6	10	10	8	8	10	8	6	6	10	10	4	2	6
	Stretch	10	6	8	8	4	6	6	6	6	6	6	4	6	10	2	8
	Compressible	4	2	2	2	2	4	2	2	2	2	2	2	2	2	8	4
MRI Properties	T1	10	4	4	4	4	4	4	4	4	10	10	10	10	0	0	10
	T2	10	6	6	6	6	6	6	4	6	6	6	6	10	0	0	10
Usability	Reusable	10	4	4	8	8	8	6	8	6	4	4	6	8	4	10	2
	Durable	8	6	6	8	10	8	8	8	8	8	8	8	8	4	4	4
	Temperature Resistant	2	6	6	10	8	8	8	8	8	6	6	8	8	4	10	2
	Ease of Preparation	8	8	8	10	2	6	6	6	6	4	4	2	4	10	8	8
	Modifiable	4	6	6	2	6	6	6	6	6	8	8	8	10	2	2	2
	Total		480	500	604	528	552	524	544	524	532	532	560	664	348	328	532

Pugh Chart
Imageable Materials

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	Total		480	500	604	528	552	524	544	524	532	532	560	664	348	328	532

Liquids

- Water
- Aqueous Solutions

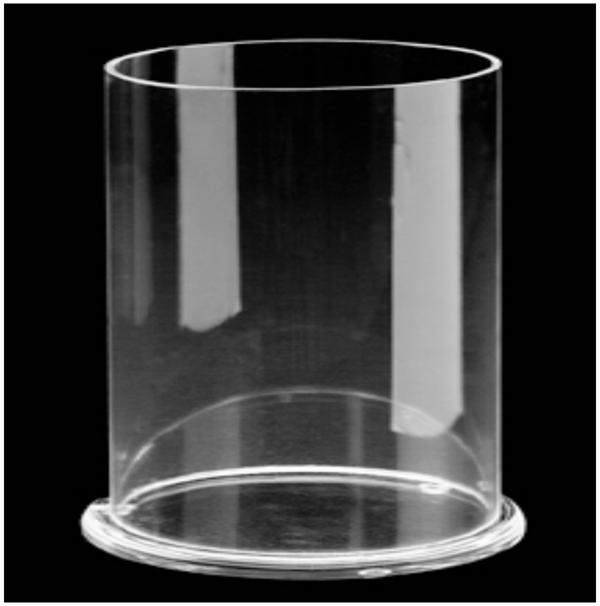
Aqueous Solutions	**T1 Equation**	**T2 Equation**
Aqueous Nickel	$T_1(s) = 1/(632\ [Ni\ (mole/L)] + 0.337)$	$T_2(s) = 1/(691\ [Ni\ (mole/L)] + 1.133)$
Nickel in 10 wt % gelatin	$T_1(s) = 1/(732\ [Ni\ (mole/L)] + 0.817)$	$T_2(s) = 1/(892\ [Ni\ (mole/L)] + 4.635)$
Aqueous Oxygen	$T_1(s) = 1/(0.013465\ [O_2\ (mg/L)] + 0.232357)$	
Aqueous Manganese	$T_1(s) = 1/(5722\ [Mn\ (mole/L)] + 0.0846)$	$T_2(s) = 1/(60386\ [Mn\ (mole/L)] + 3.644)$
Aqueous Copper	$T_1(s) = 1/(606\ [Cu\ (mole/L)] + 0.349)$	$T_2(s) = 1/(850\ [Cu\ (mole/L)] + 0.0357)$

Liquids

- Oil
- Silicone Oil
  - Low T_2 relaxation times
  - Add small amounts of non-ionic paramagnetic compounds (gadolinium beta-diketonate) to reduce T_1
    - Dissolves with vigorous stirring and/or gentle heating

Non-Imageable Materials

- Shells
  - Commercial Diagnostic Thoracic Phantom
  - Polymethyl methacrylate (Plexiglas)
  - Polyoxymethylene (Delrin)
- Tumor Insets
  - Rubber
  - Plastic
  - Glass



Motion

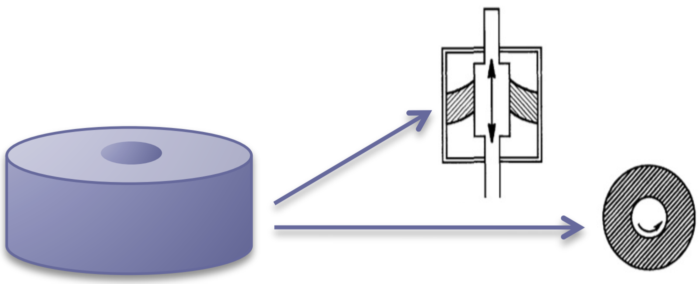
Existing Solutions

- Annulus
- Gel Cylinder
- Compressed foam
- K'nex Model

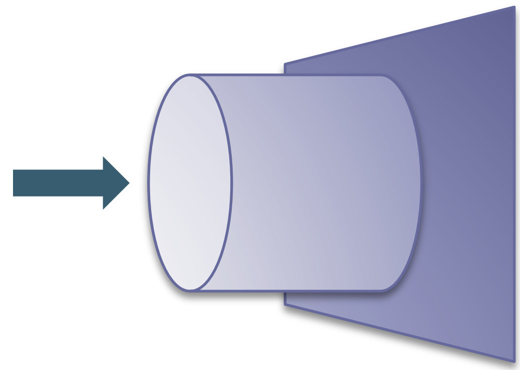
Original Designs

- Telescoping Canisters
- Fluid Pump
- Drum Head
- Stacked Disc
- Elastic Box
- Compressed Foam

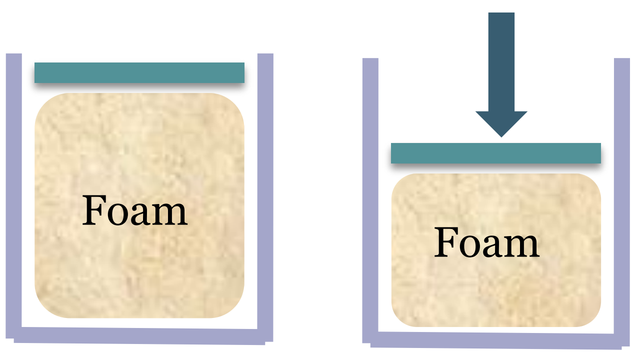
Motion – Existing Solutions



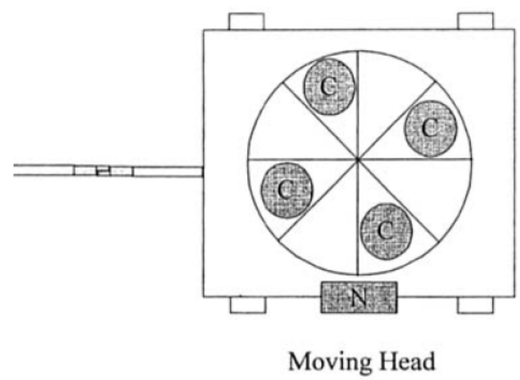
Drangova (1996)



Kee (2010)



Kashani (2006)

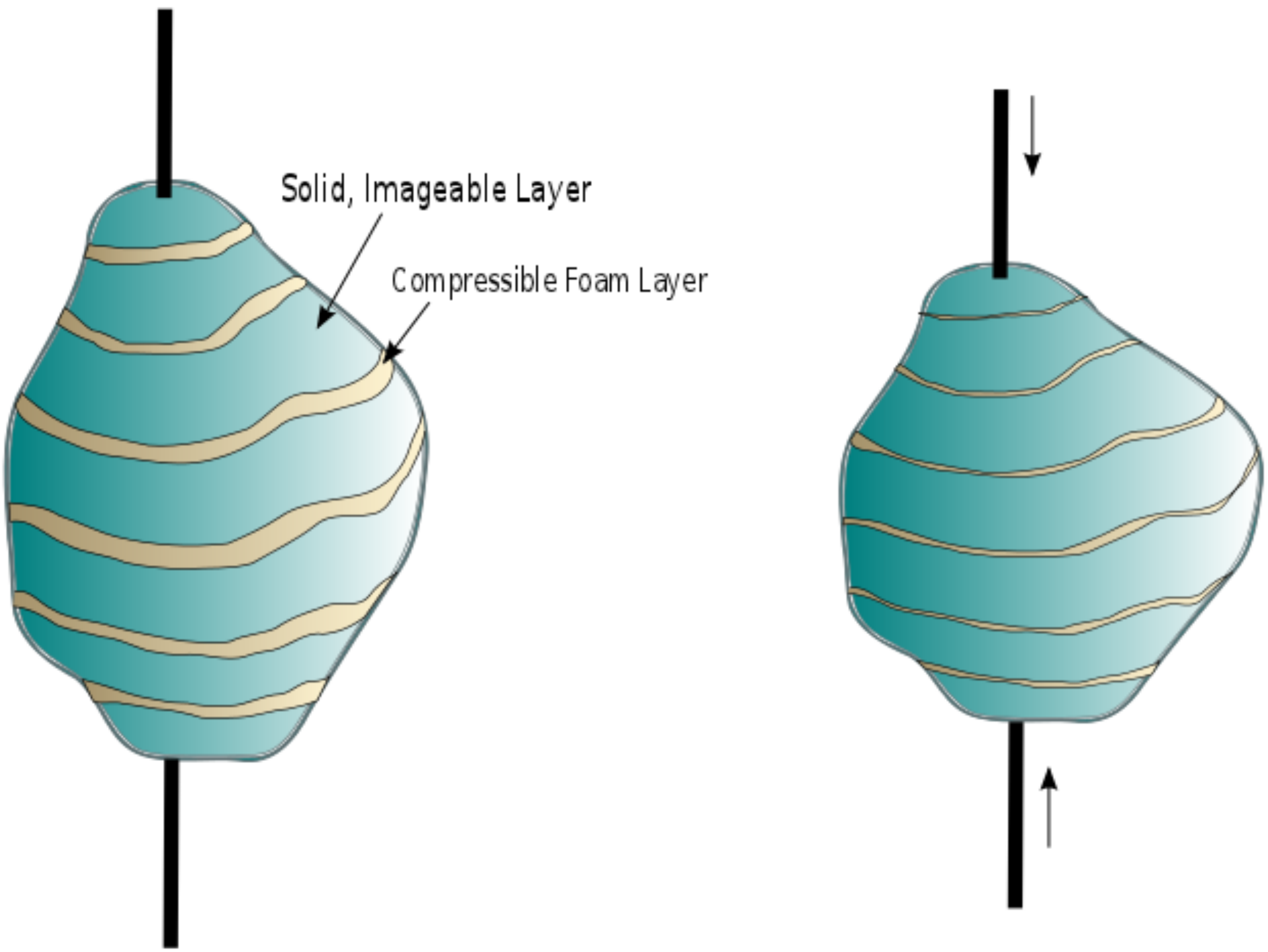


K'Nex Model

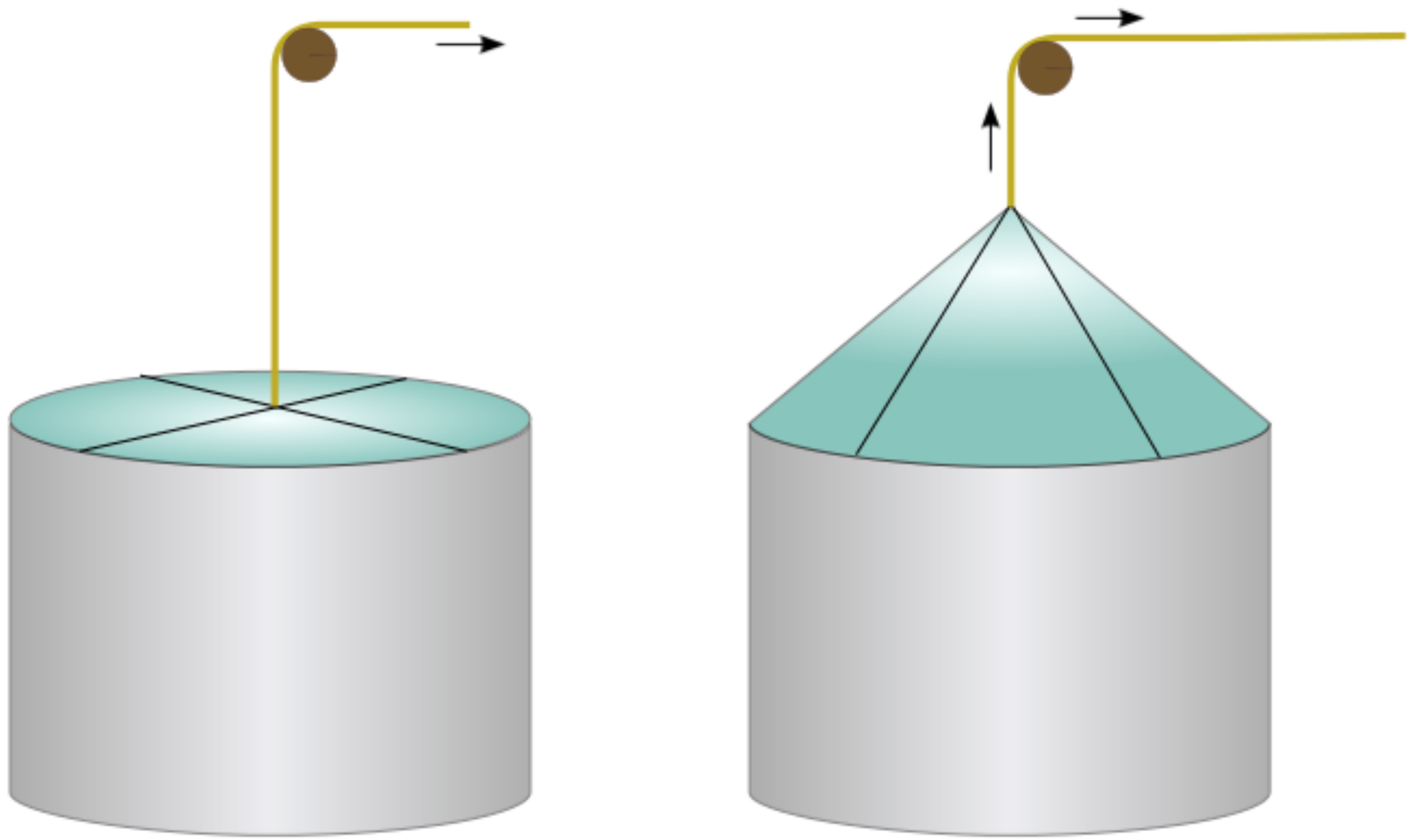
Pugh Chart
Motion Mechanisms- Existing Solutions

		Weighing Factor	Annulus on Torqued Axle	Gel Cylinder Deformed with Piston	Iodized Foam Depressed with Piston	K'nex Model
Motion Types	3D Translation (5 ± 0.5 cm)	10	3	3	0	3
	3D Deformation (2 ± 0.5 cm)	8	9	7	3	0
	3D Rotation (± 0.5°)	3	3	3	0	3
	Volume Change (25% max)	9	0	1	10	0
Motion Characteristics	Stable and Reproducible	10	9	10	10	1
	Time Resolution ≈ 0.1 ms	9	10	10	10	3
Motion Actuator	Simplicity	8	7	7	10	10
	Non-Interfering in MRI	8	7	10	4	10
Physical Characteristics	Weight ≤ 150 lbs	3	10	10	10	10
	Size ≤ 50x30x50 cm	3	10	10	3	5
	Cost $10,000 - $30,000	2	9	9	6	10
Qualitative Characteristics	Organ-Like Shape	3	6	7	10	8
	Tissue-Like Relaxation Parameters	7	10	8	0	10
	Total		569	585	497	395

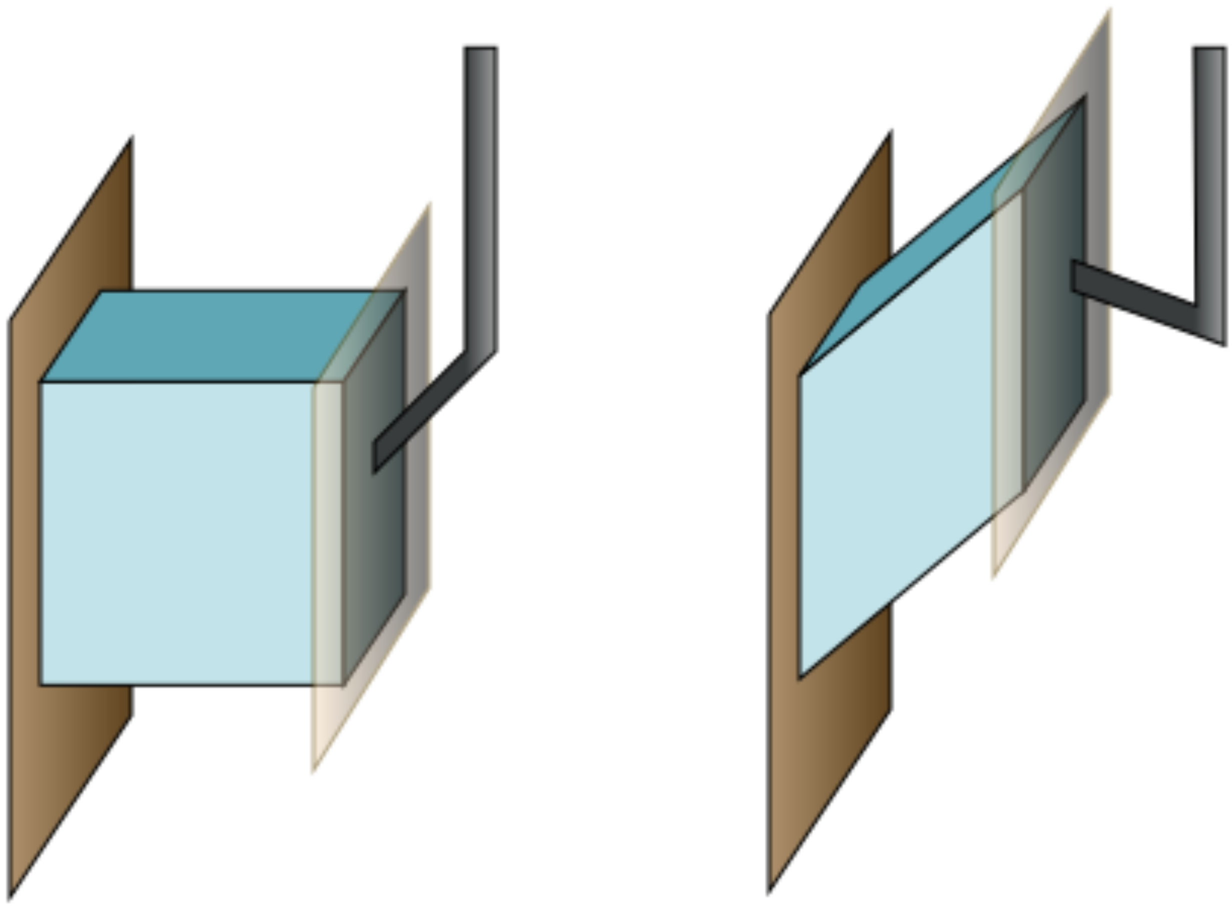
Stacked Disc



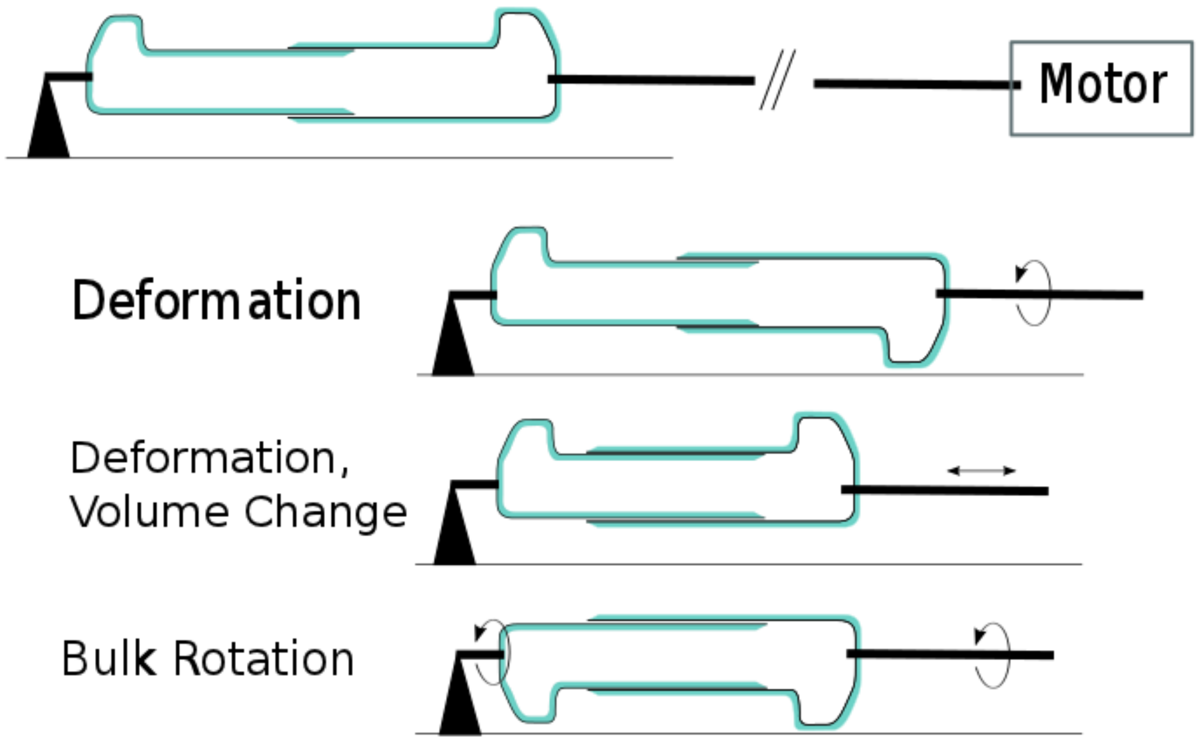
Drum Head



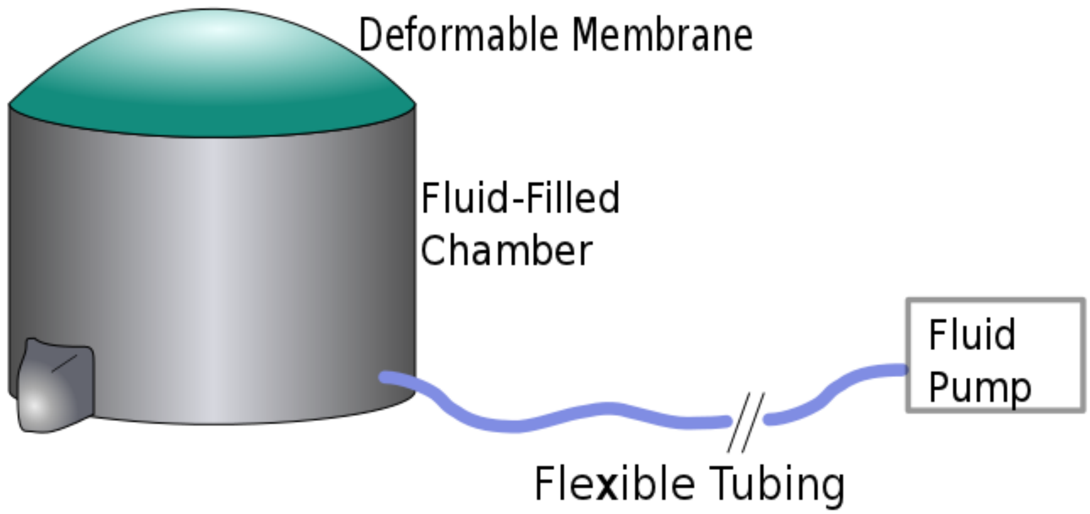
Elastic Box

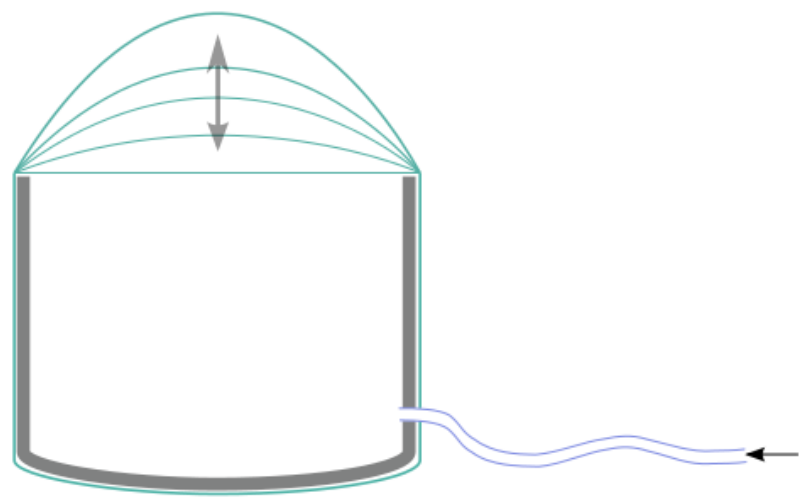


Telescoping Canisters



Fluid Pump


Deformable Membrane
Fluid-Filled
Chamber
Fluid
Pump
Flexible Tubing



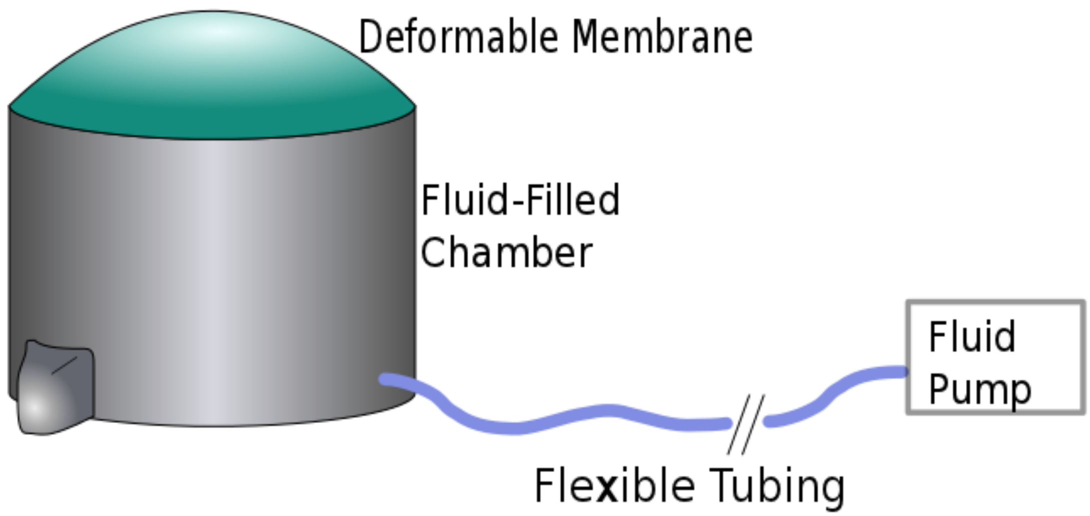
Pugh Chart

Motion Mechanisms-
Unique Models

		Weighting Factor	Telescoping Canisters	Fluid Pump-Imageable Liquid	Fluid Pump-Imageable Membrane	Drum Head	Stacked Disc	Elastic Box	Compressed Foam
Motion Types	3D Translation (5 ± 0.5 cm)	10	10	7	7	10	10	3	10
	3D Deformation (2 ± 0.5 cm)	8	6	10	10	10	3	10	3
	3D Rotation (± 0.5°)	3	4	4	4	6	5	0	3
	Volume Change (25% max)	9	7	10	10	10	5	10	10
Motion Characteristics	Stable and Reproducible	10	9	10	10	8	1	1	7
	Time Resolution ≈ 0.1 ms	9	10	7	7	10	2	1	10
Motion Actuator	Simplicity	8	4	10	10	10	3	3	6
	Non-Interfering in MRI	8	9	10	10	10	10	4	10
Physical Characteristics	Weight ≤ 150 lbs	3	10	10	10	10	10	10	10
	Size ≤ 50x30x50 cm	3	10	10	10	10	10	8	10
	Cost $10,000 - $30,000	2	9	6	6	9	4	9	6
Qualitative Characteristics	Organ-Like Shape	3	10	9	9	6	10	2	9
	Tissue-Like Relaxation Parameters	7	10	5	5	0	4	8	0
	Total		585	639	639	614	342	379	510

Design Choice

Fluid Pump – Imageable Liquid



Fluid Pump Elements

- Materials
  - Elastic membrane (Silicone Membrane)
  - Imageable liquid (Silicone Oil)
  - Non-imageable casing (Plexiglas, Delrin)
  - Flexible tubing
- Fluid Pump
- Motion Actuators
  - Translational/Rotational stage

Fluid Pump Analysis

- Material
  - Membrane
    - Membrane elastic properties
    - Maximum stretch and strain
    - General equations for deformation of a membrane (displacement)
  - Calculate relaxation times for Silicone Oil

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  - Slow speed and appropriate volume
  - Equations to describe volume pushed into phantom at every time

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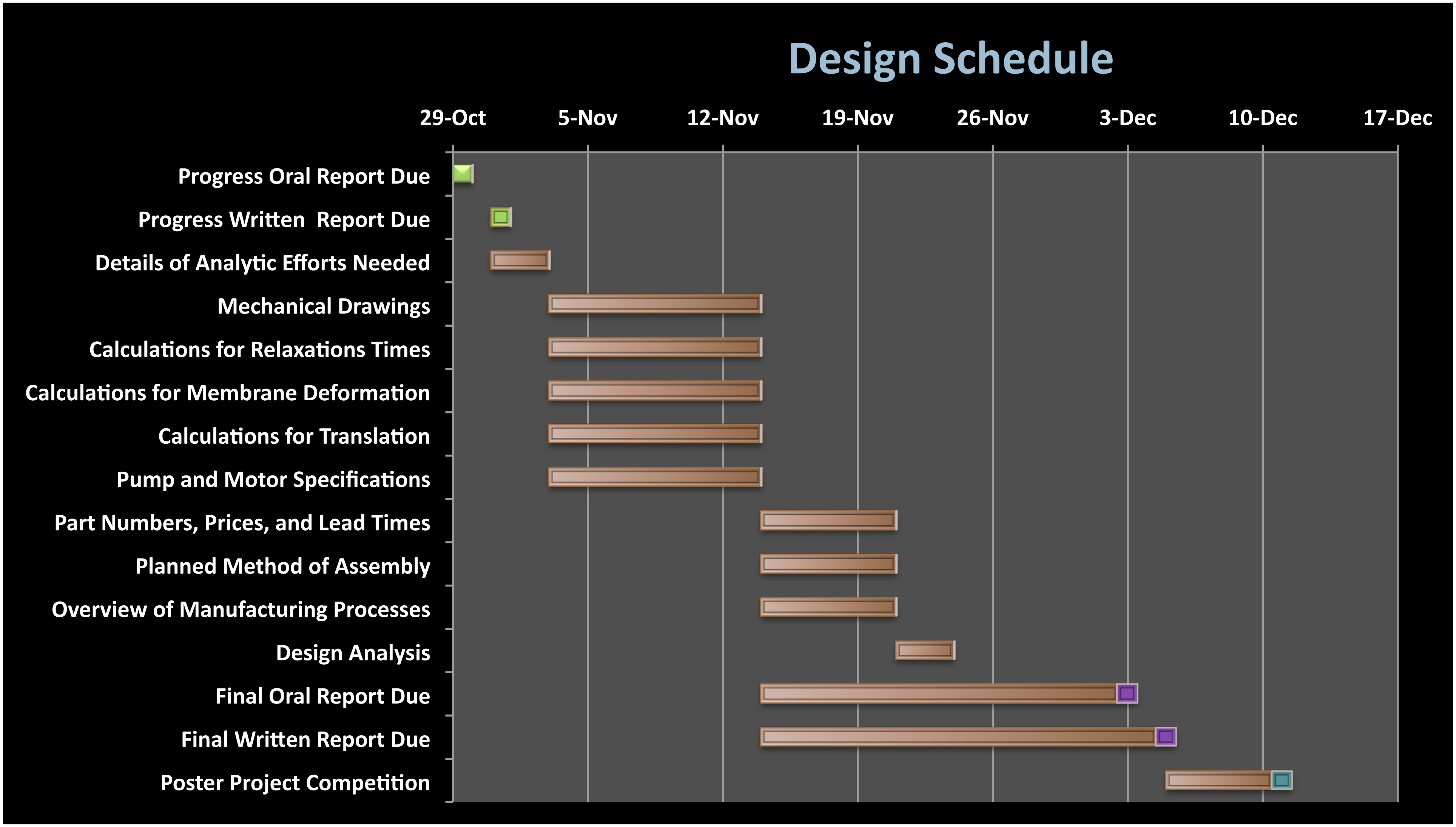
  - Equations to describe motion of motion stage (position)
- Motor
  - Previous designs (Zhou 1999, Kee 2010)
  - Calculate safe distance for motor


Design Schedule
29-Oct
5-Nov
12-Nov
19-Nov
26-Nov
3-Dec
10-Dec
17-Dec
Progress Oral Report Due
Progress Written Report Due
Details of Analytic Efforts Needed
Mechanical Drawings
Calculations for Relaxations Times
Calculations for Membrane Deformation
Calculations for Translation
Pump and Motor Specifications
Part Numbers, Prices, and Lead Times
Planned Method of Assembly
Overview of Manufacturing Processes
Design Analysis
Final Oral Report Due
Final Written Report Due
Poster Project Competition

Team Responsibilities

Jacie Sales	Leah Laux
Mechanical drawings	Pump analysis
Calculations for silicone oil relaxation times	Motor analysis
Calculations for Membrane Deformation	Part numbers, prices, lead times
Calculations for Translation/Rotation	Assembly/Manufacturing
Final written report	Final oral report
Poster project	

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