In-Mold Assembly: A New Approach to Assembly Automation

**Goals**
- Develop mold design templates to develop mesoscale joints
- Develop model to estimate deformation of premolded components and alternate ways to control it
- Develop an understanding of in-mold assembly clearances
- Develop design templates to embed electronics and actuators in mold
- Develop models to understand heat dissipation of actuators embedded in polymers

**Process Characterization and Modeling**

**Unidirectional Filling for In-Mold Assembly of Mesoscale Revolute Joints**
- First stage melt flows from Gate 1
- Second stage melt flows from Gate 2
- Plastic deformation of premolded components

**Bi-directional Filling for In-Mold Assembly of Mesoscale Revolute Joints**
- Bi-directional filling
- Gate 1 and Gate 2
- Weld lines
- Deformation of premolded components

**Joint Clearances during In-Mold Assembly of Mesoscale Revolute Joints**
- Change in premolded component dimensions due to second stage melt flow
- Premolded component undergoes axial plastic deformation due to compressive force applied by second stage polymer melt forming assembly clearances

**Bi-directional Filling for In-Mold Assembly of Mesoscale Revolute Joints**
- Gate 1
- Gate 2
- Weld lines
- Deformation of premolded components

**Capabilities**
- Bi-directional filling
- Gate 1 and Gate 2
- Weld lines
- Deformation of premolded components

**Applications**
- **Flapping Wing MAV**
  - AML has built several versions of flapping wing MAVs using advances in injection molding. Molded drive mechanism converts rotary motor motion to flapping action for wings.
  - In-mold assembly methods used to:
    - Automate assembly process
    - Eliminate fasteners
    - Decrease weight

**Miniature Robot**
- Shape memory alloy (SMA) actuated robot developed by AML in collaboration with Robotics Automation Manipulation and Sensing (RAMS) Lab
- In-mold assembly methods used to:
  - Downscale overall robot size
  - Significantly reduce part count
  - Eliminate fasteners

**In-Mold Assembly Concept**
- Traditional design created by machining and manual assembly
- Consists of 11 parts and 10 assembly operations
- New design enabled by in-mold assembly
- Consists of 5 pieces and no assembly operation

**Research results:**
- 40% reduction in the operating temperature of the embedded actuator
- Polymers with $k > 2 \text{ W/m-K}$ do not require orthotropic thermal conductivity modeling

**Embedding Actuators**
- We use thermally conductive polymer composites to create multi-functional structures with embedded actuators
- Anchoring of the embedded actuator
- Dissipation of heat produced by the actuator
- Coupled modeling approach:
  - Polymer melt flow inside the mold to obtain fiber orientations
  - Orthotropic thermal conductivity models from molding process to assess heat dissipation
  - Research results:
    - Polymers
  - Premolded component deformation dependent on temporal misalignment of gates

**In-Mold Assembly Concept**
- Part comes out of the mold fully assembled

**Mesoscale in-mold assembly methods utilized to manufacture 25 DOF hand**
- SMA actuated robot suitable for Neurosurgery

**Joint Clearances during In-Mold Assembly of Mesoscale Revolute Joints**
- Change in premolded component dimensions due to second stage melt flow
- Premolded component undergoes axial plastic deformation due to compressive force applied by second stage polymer melt forming assembly clearances

**Joint Clearances during In-Mold Assembly of Mesoscale Revolute Joints**
- Change in diameter ($D_c$) of the premolded component found to be related to support cavity length ($L_c$)

**In-Mold Assembly Concept**
- Traditional design created by machining and manual assembly
- Consists of 11 parts and 10 assembly operations
- New design enabled by in-mold assembly
- Consists of 5 pieces and no assembly operation

**Research results:**
- 40% reduction in the operating temperature of the embedded actuator
- Polymers with $k > 2 \text{ W/m-K}$ do not require orthotropic thermal conductivity modeling

**Embedding Actuators**
- We use thermally conductive polymer composites to create multi-functional structures with embedded actuators
- Anchoring of the embedded actuator
- Dissipation of heat produced by the actuator
- Coupled modeling approach:
  - Polymer melt flow inside the mold to obtain fiber orientations
  - Orthotropic thermal conductivity models from molding process to assess heat dissipation
  - Research results:
    - Polymers
  - Premolded component deformation dependent on temporal misalignment of gates

**In-Mold Assembly Concept**
- Part comes out of the mold fully assembled

**Joint Clearances during In-Mold Assembly of Mesoscale Revolute Joints**
- Change in premolded component dimensions due to second stage melt flow
- Premolded component undergoes axial plastic deformation due to compressive force applied by second stage polymer melt forming assembly clearances

**Joint Clearances during In-Mold Assembly of Mesoscale Revolute Joints**
- Change in diameter ($D_c$) of the premolded component found to be related to support cavity length ($L_c$)

**In-Mold Assembly Concept**
- Traditional design created by machining and manual assembly
- Consists of 11 parts and 10 assembly operations
- New design enabled by in-mold assembly
- Consists of 5 pieces and no assembly operation

**Research results:**
- 40% reduction in the operating temperature of the embedded actuator
- Polymers with $k > 2 \text{ W/m-K}$ do not require orthotropic thermal conductivity modeling

**Embedding Actuators**
- We use thermally conductive polymer composites to create multi-functional structures with embedded actuators
- Anchoring of the embedded actuator
- Dissipation of heat produced by the actuator
- Coupled modeling approach:
  - Polymer melt flow inside the mold to obtain fiber orientations
  - Orthotropic thermal conductivity models from molding process to assess heat dissipation
  - Research results:
    - Polymers
  - Premolded component deformation dependent on temporal misalignment of gates

**In-Mold Assembly Concept**
- Part comes out of the mold fully assembled

**Joint Clearances during In-Mold Assembly of Mesoscale Revolute Joints**
- Change in premolded component dimensions due to second stage melt flow
- Premolded component undergoes axial plastic deformation due to compressive force applied by second stage polymer melt forming assembly clearances

**Joint Clearances during In-Mold Assembly of Mesoscale Revolute Joints**
- Change in diameter ($D_c$) of the premolded component found to be related to support cavity length ($L_c$)

**In-Mold Assembly Concept**
- Traditional design created by machining and manual assembly
- Consists of 11 parts and 10 assembly operations
- New design enabled by in-mold assembly
- Consists of 5 pieces and no assembly operation

**Research results:**
- 40% reduction in the operating temperature of the embedded actuator
- Polymers with $k > 2 \text{ W/m-K}$ do not require orthotropic thermal conductivity modeling

**Embedding Actuators**
- We use thermally conductive polymer composites to create multi-functional structures with embedded actuators
- Anchoring of the embedded actuator
- Dissipation of heat produced by the actuator
- Coupled modeling approach:
  - Polymer melt flow inside the mold to obtain fiber orientations
  - Orthotropic thermal conductivity models from molding process to assess heat dissipation
  - Research results:
    - Polymers
  - Premolded component deformation dependent on temporal misalignment of gates

**In-Mold Assembly Concept**
- Part comes out of the mold fully assembled

**Joint Clearances during In-Mold Assembly of Mesoscale Revolute Joints**
- Change in premolded component dimensions due to second stage melt flow
- Premolded component undergoes axial plastic deformation due to compressive force applied by second stage polymer melt forming assembly clearances

**Joint Clearances during In-Mold Assembly of Mesoscale Revolute Joints**
- Change in diameter ($D_c$) of the premolded component found to be related to support cavity length ($L_c$)

**In-Mold Assembly Concept**
- Traditional design created by machining and manual assembly
- Consists of 11 parts and 10 assembly operations
- New design enabled by in-mold assembly
- Consists of 5 pieces and no assembly operation

**Research results:**
- 40% reduction in the operating temperature of the embedded actuator
- Polymers with $k > 2 \text{ W/m-K}$ do not require orthotropic thermal conductivity modeling

**Embedding Actuators**
- We use thermally conductive polymer composites to create multi-functional structures with embedded actuators
- Anchoring of the embedded actuator
- Dissipation of heat produced by the actuator
- Coupled modeling approach:
  - Polymer melt flow inside the mold to obtain fiber orientations
  - Orthotropic thermal conductivity models from molding process to assess heat dissipation
  - Research results:
    - Polymers
  - Premolded component deformation dependent on temporal misalignment of gates

**In-Mold Assembly Concept**
- Part comes out of the mold fully assembled

**Joint Clearances during In-Mold Assembly of Mesoscale Revolute Joints**
- Change in premolded component dimensions due to second stage melt flow
- Premolded component undergoes axial plastic deformation due to compressive force applied by second stage polymer melt forming assembly clearances

**Joint Clearances during In-Mold Assembly of Mesoscale Revolute Joints**
- Change in diameter ($D_c$) of the premolded component found to be related to support cavity length ($L_c$)