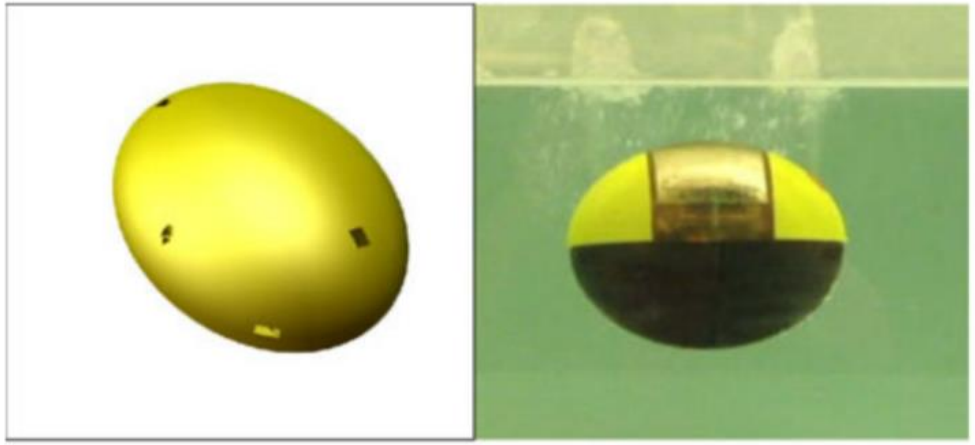
Omni-Egg

- Design constraints
  - 14.6cm by 10.8cm
- Symmetric body shape
- Symmetric four jet configuration
- Appendage free design



Propulsion

- Pump configurations
- Coanda valves
- Pump types

Power

- 11V lithium Polymer

Controls

- 3-axis IMU
- Pressure sensor

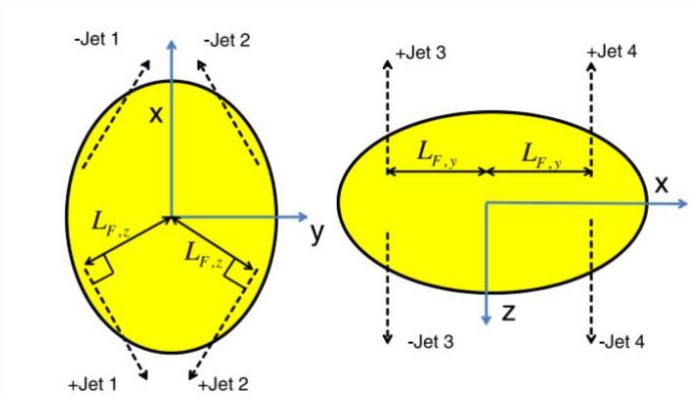
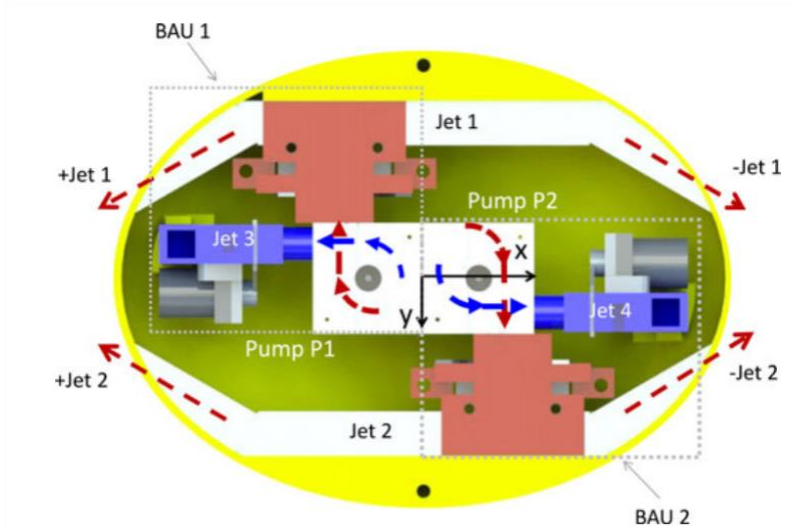
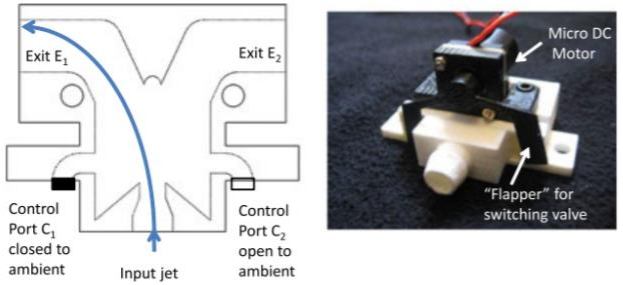
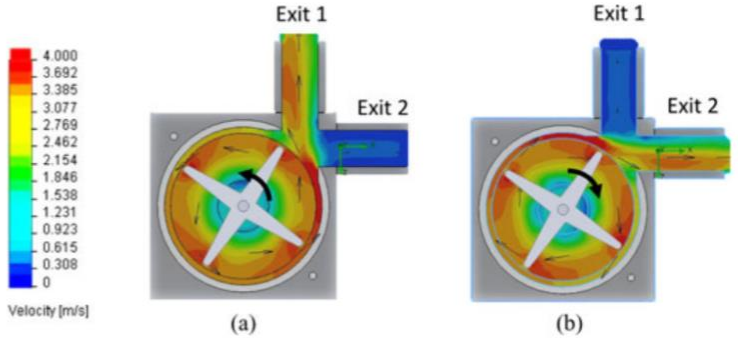


Fig. 2. Conceptual jet arrangement for achieving 5 DOF maneuvering.







Dynamic Analysis

- Considered different pump layouts
- Modeled three different motions
  - Stationary, longitudinal and lateral movements
- Eigenvalues of the system matrix give insight to the stability
  - Zeros and poles of the transfer function
- Controllability Gramian
  - Full rank

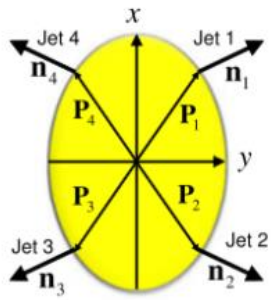


Fig. 3. Visual illustration of the jet coordinate system and naming convention.

Effect on Design

- Jet direction cannot be aligned with longitudinal axis
- Body shape cannot be completely spherical
- Line of action of jets cannot pass through the center of mass
- The moment coefficient cannot be negative

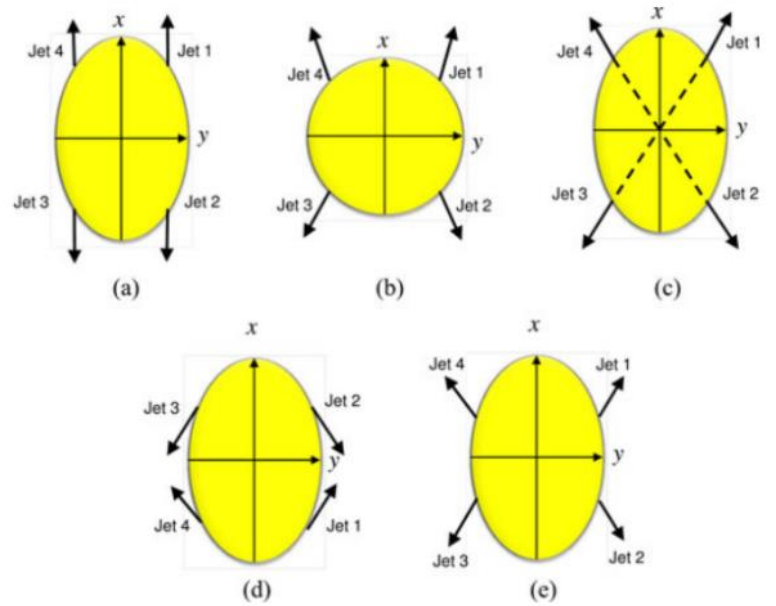


Fig. 5. Illustrations of five special configurations that have issues with controllability. (a) Uncontrollable longitudinal dynamics due to jets. (b) Uncontrollable longitudinal dynamics due to shape. (c) Uncontrollable quasi-stationary dynamics due to jets. (d) Right half plane zeroes due to $c < 0$. (e) Right half plane zeroes due to $c < 0$.

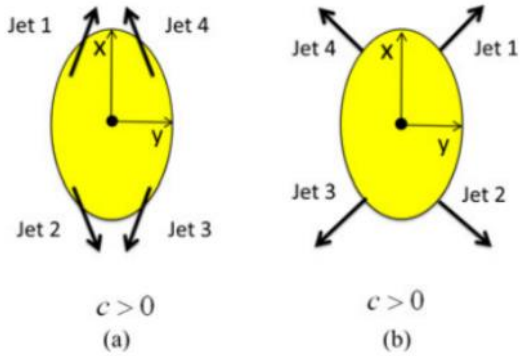


Fig. 6. Illustration of the two jet configurations that provide desired control properties.

Vehicle Shape

- Degree of controllability
- Maximize moment coefficient
  - Jet tangent to the ellipsoidal shape
- Jet angle
  - Large angle increases longitudinal control
  - Reduces efficiency
- Aspect ratio
  - Between 1.15 and 1.77 give high controllability
  - Small increases cause large drop in drag

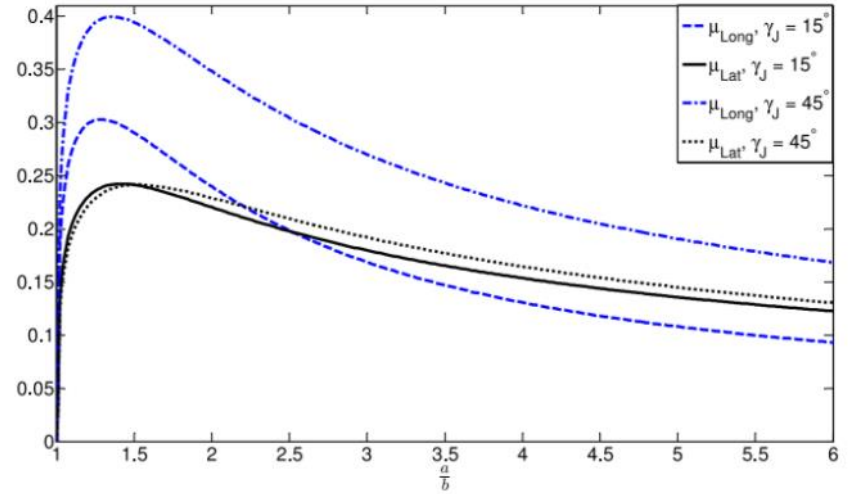


Fig. 7. Illustration of the effect of jet angle, γ_J, and the aspect ratio, $\frac{a}{b}$, on the controllability metrics, $\mu_{\mathrm{Long}}, \mu_{\mathrm{Lat}}$.

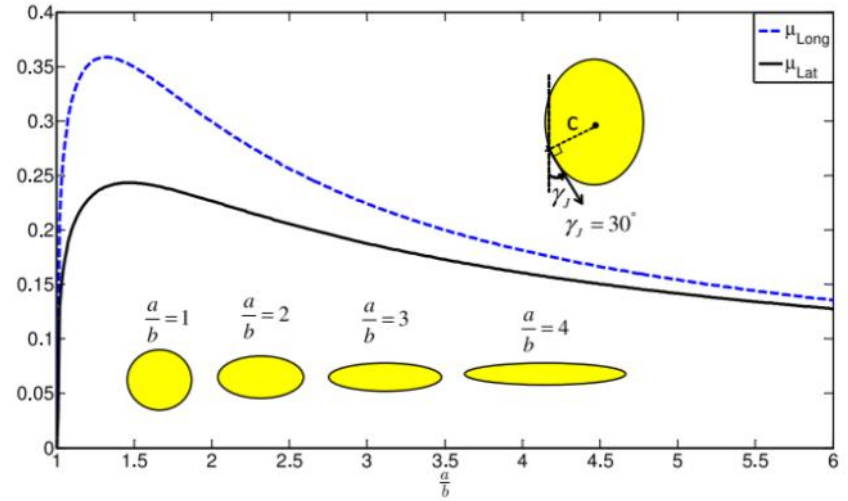


Fig. 8. Illustration of the degrees of controllability, μ_{Long} and μ_{Lat} for the longitudinal and lateral motions, respectively, when $\gamma_J = 30^\circ$.

Robot Design

- Propulsion
  - Pump layout
- Power
  - Lithium polymer
- Controls
  - Depth sensor, 6-axis IMU
  - Closed loop control on yaw angle and yaw rate
  - PD control

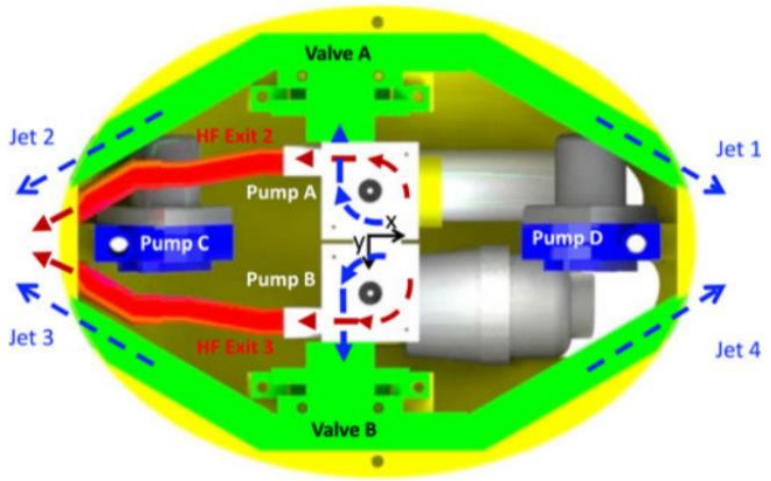


Fig. 10. Rendering illustrating the propulsion architecture.

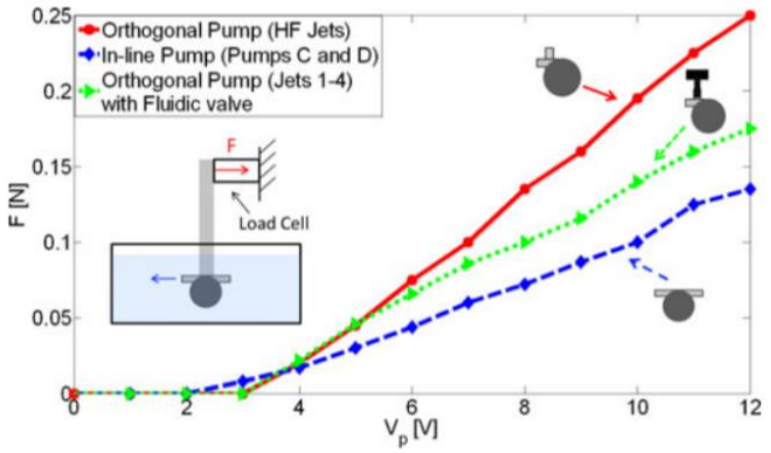
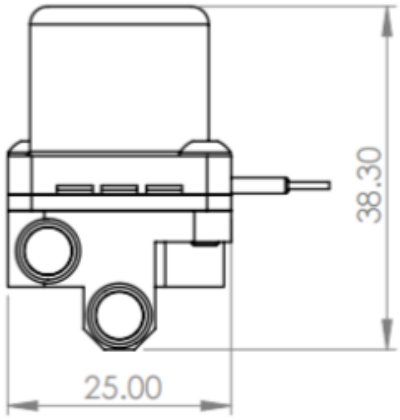
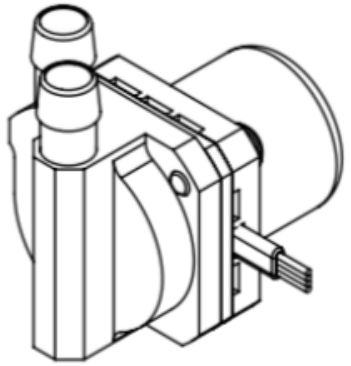


Fig. 11. Experimental force data for three pump-valve systems used in the robot maneuvering system.

Pumps





- Centrifugal
  - Widely available
  - Small sizes
  - Best efficiency point
- Positive Displacement
  - Low flow rate allows for high accuracy
  - Will produce the same flow rate for all pump head outputs
  - Reversible flow
- TCS Micropumps