QUANTUM DYNAMICS ENTERPRISES, INC.
— PROPELLING US TOWARDS THE FUTURE —

Centrifugal Impulse Drive (CID®) modeling

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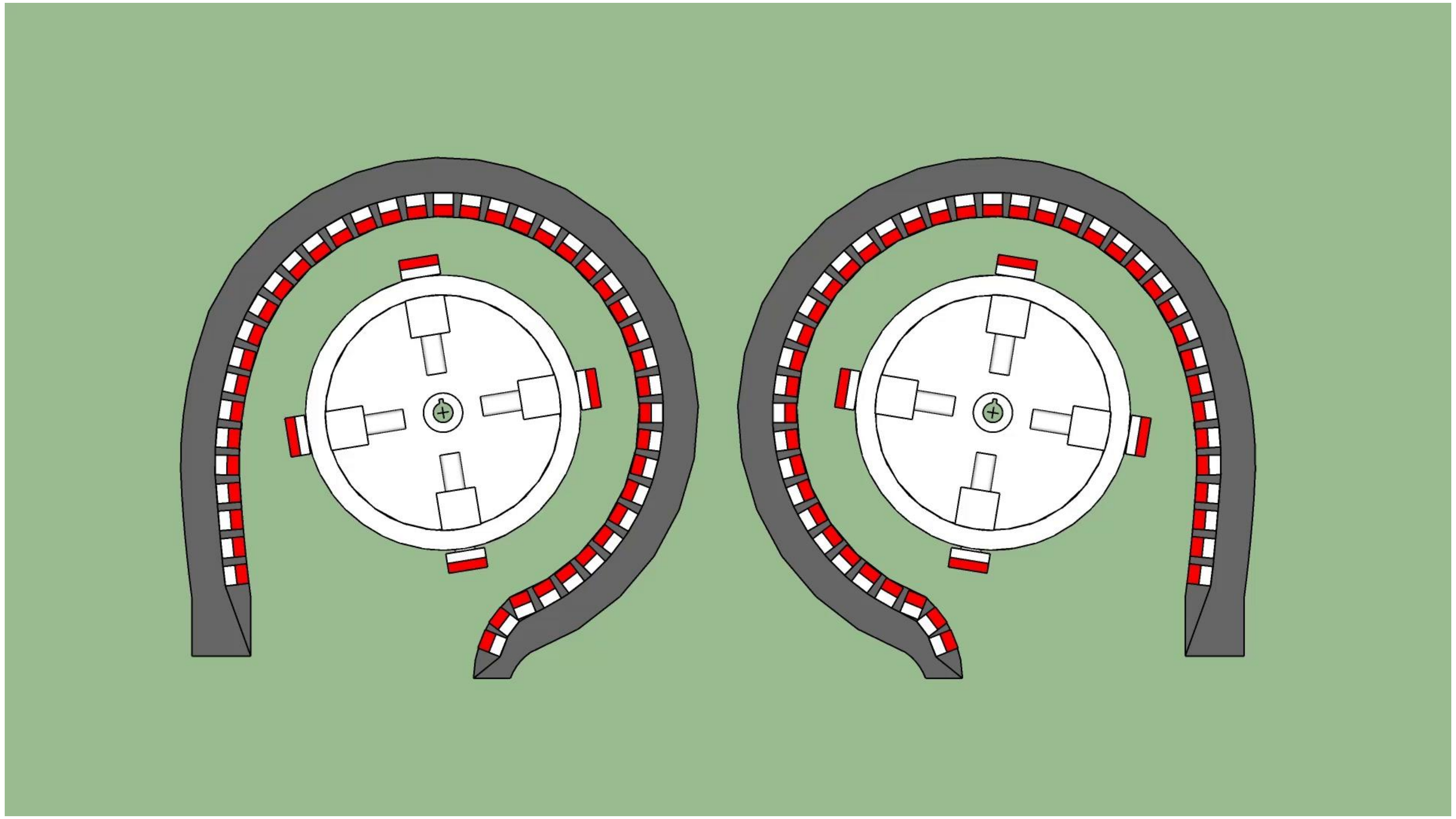
Shakeeb Bin Hasan, PhD

Freelance physicist and researcher in electromagnetics

- PhD in Physics (optics) from Friedrich-Schiller-University Jena, Germany
- More than ten years of deep-tech research in academia and industry related to:
  - semiconductor metrology using both light and electron beams
  - semiconductor optoelectronic devices
  - electromechanical drives
  - optical/photonic system design and analysis
  - application of machine learning and optimization methods to physical problems
- Co-author/co-inventor in many peer-reviewed publications/patents (scholar profile)
- Contact at linkedin or s.b.hasan@simaxis.co to discuss potential collaboration

Introduction to CID®

Converting rotational momentum to linear motion



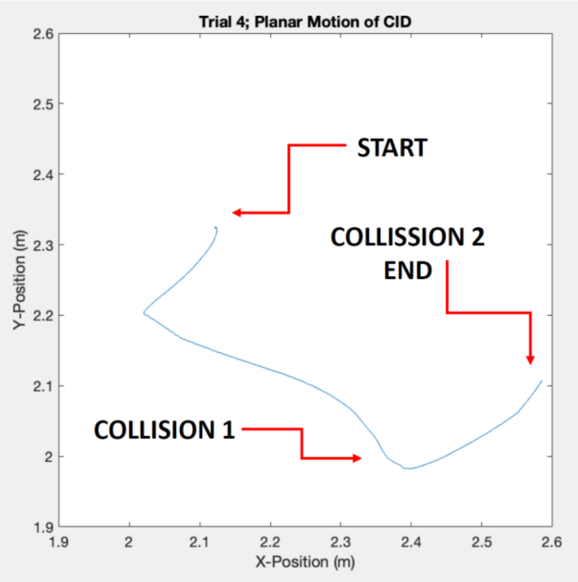
Illustrative animation of CID at work

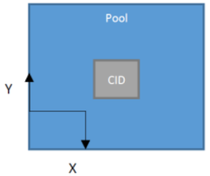
Experimental demonstration

Device can perform net linear and rotational motion

Georgia Tech Position Summary Data **HPEPL** High-Power Electric Propulsion Laboratory

- **Trial 4** demonstrated net translational + rotational motion.





Average magnitude of Force	4.229 mN
Test Duration	7:19
Target Speed	245 RPM
Speed Range	245-238 RPM

The CID grazed the pool wall at first, but then collided a second time that caused enough disruption to end the trial.

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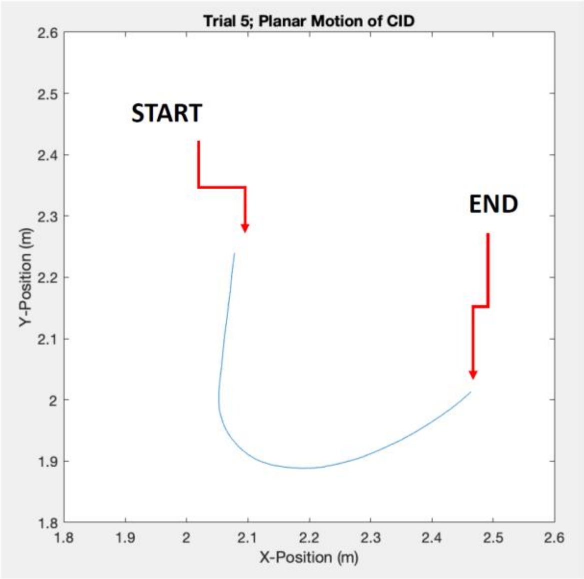
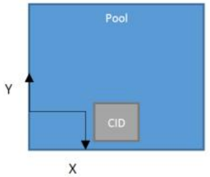
Georgia Tech Position Summary Data **HPEPL** High-Power Electric Propulsion Laboratory

- **Trial 5** demonstrated net translational + rotational motion.





Average magnitude of Force	4.027 mN
Test Duration	3:23
Target Speed	240 RPM
Speed Range	240-233 RPM

First time using one of the Milwaukee batteries; this one seems to discharge faster. We ceased the trail once the RPM's dipped to the low 230s.

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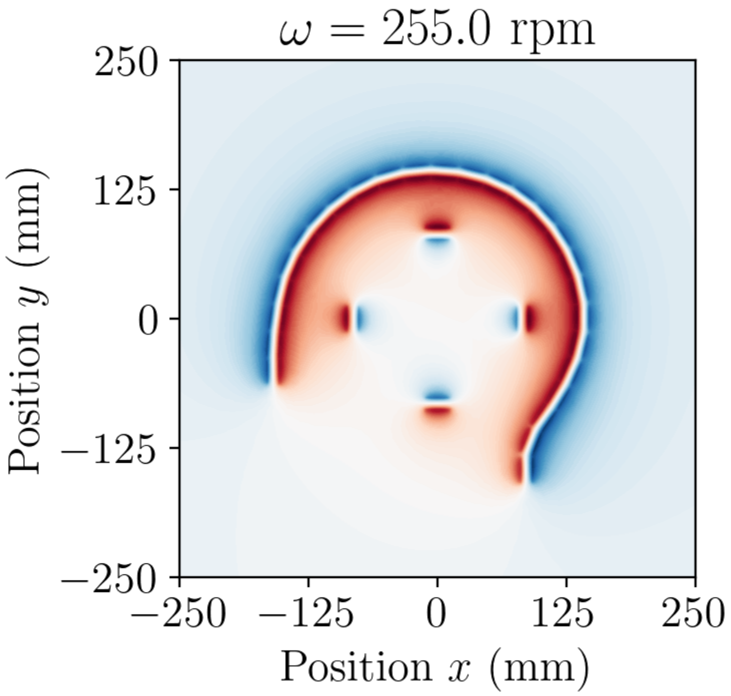
Physical model of the CID®

Exact geometry and realistic physical assumptions

- Magnets operate in linear, instantaneous regime (no hysterisis)
- Individual rings in the CID® do not magnetically interfere with each other
- Operating frequency is small enough to ignore time derivatives in Maxwell's equations
- Friction is ignored



Physical model of the CID®

Stationary fields and linear, instantaneous magnetic response

- Considering low frequencies and the absence of current sources/Eddy currents:

$$\nabla \times \mathbf{H}(\mathbf{r},t) \approx 0 \qquad \mathbf{H}(\mathbf{r},t) = -\nabla V_{\mathrm{m}}(\mathbf{r},t)$$

V_m is the scalar magnetic potential we solve for

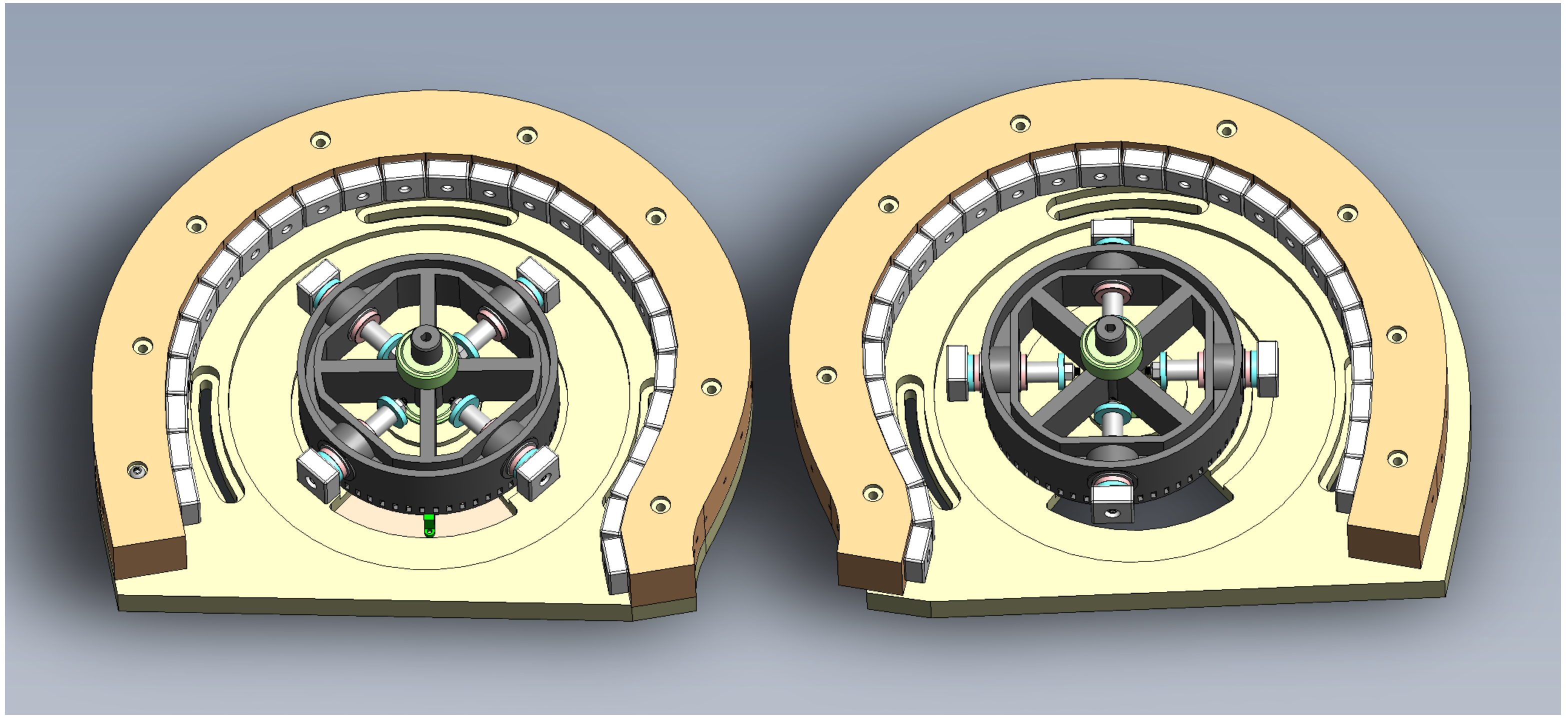
$$\mathbf{B}(\mathbf{r},t) = \mu(\mathbf{r})\mathbf{H}(\mathbf{r},t) + \mathbf{B}_{\mathrm{rem}}(\mathbf{r})$$

B_{rem} is the remnant flux density inside permanent magnets

- The resulting Poisson equation for V_m is solved using opensource FEM solver FEniCSx

CAD model of the CID®

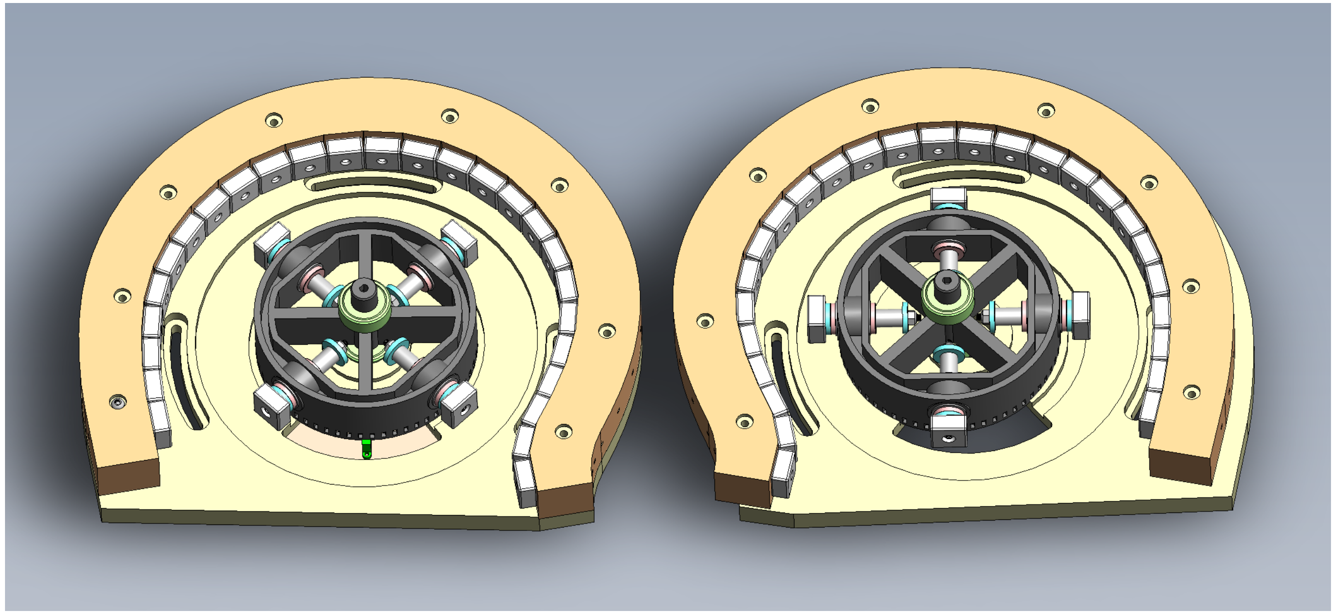
Single ring-rotor geometry

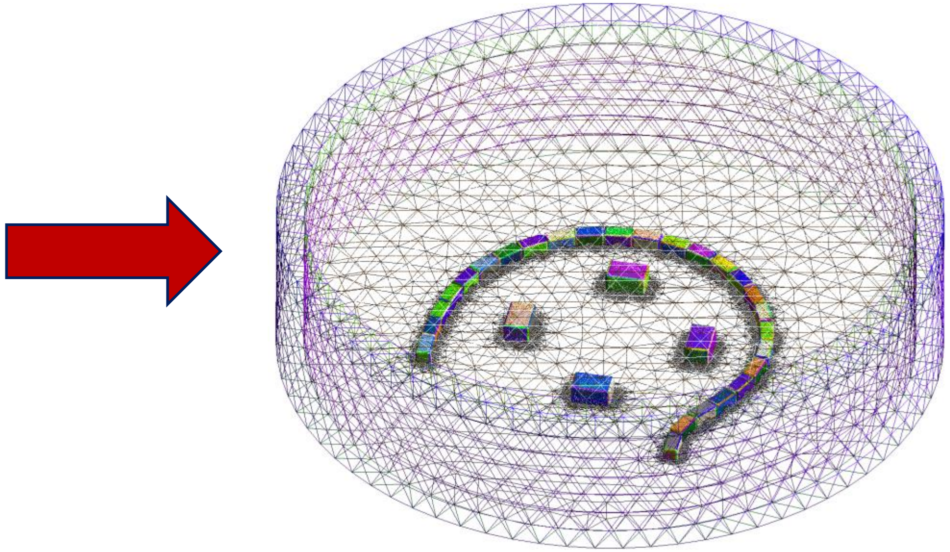


Since magnetic interaction between the two ring-rotor geometries is insignificant, we can simplify analysis by modeling only one

Mesh model of the CID®

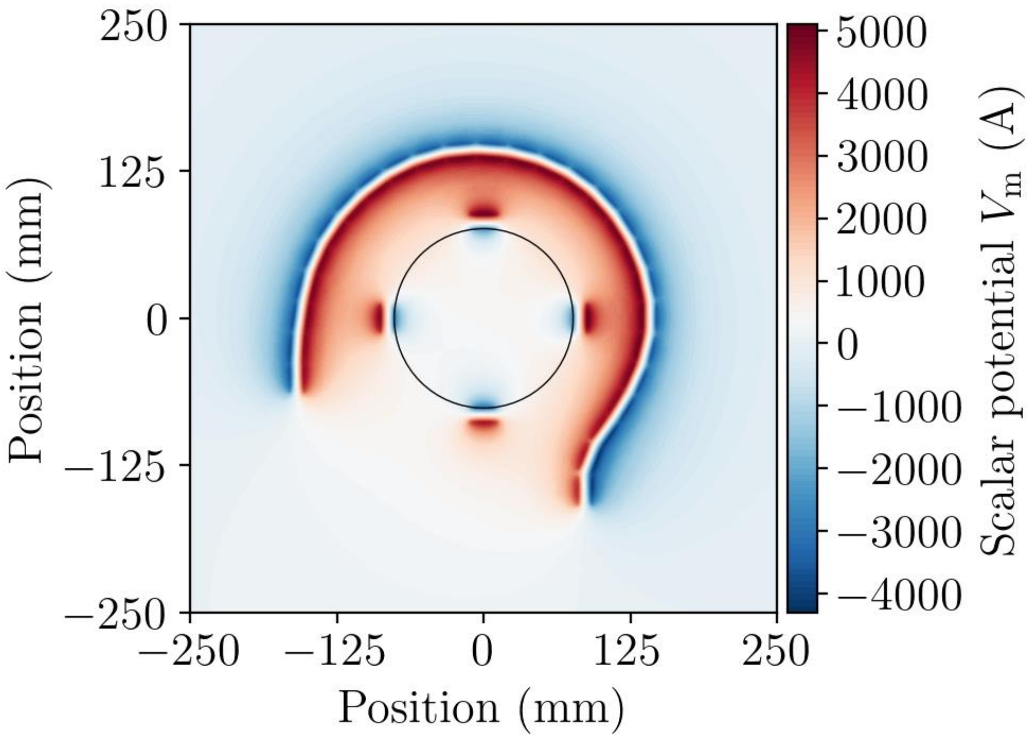
FEM model comprises only single ring-rotor geometry

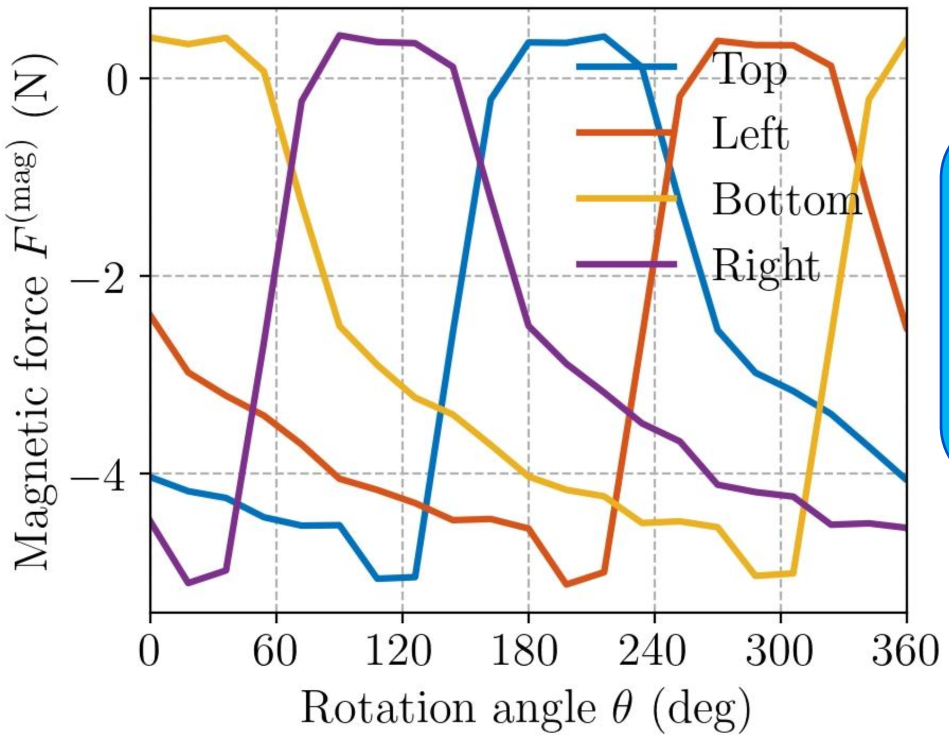




Stationary FEM model of the CID®

Scalar potential and magnetic forces





Legend identifies magnets with respect to their initial positions at 0 deg rotation

Magnetic force in radial direction experienced by each rotor magnet at different angular positions

Transient model of the CID® (1/3)

Coupling stationary magnetic model with equations of motion

- Linear motion of individual magnets:

$$\frac{\mathrm{d}\boldsymbol{r}_j}{\mathrm{d}t} = \boldsymbol{v}_j \qquad\qquad m\frac{\mathrm{d}\boldsymbol{v}_j}{\mathrm{d}t} = \boldsymbol{F}_j^{(\mathrm{mag})} + \boldsymbol{F}_j^{(\mathrm{cfg})}$$

- $F_j^{(\mathrm{mag})}$ denotes magnetic while $F_j^{(\mathrm{cfg})}$ centrifugal forces

- Both magnetic and centrifugal forces are calculated in the rotating frame

Transient model of the CID® (2/3)

Coupling stationary magnetic model with equations of motion

- Linear motion of the CID:

$$\frac{\mathrm{d}\mathbf{r}^{(\mathrm{CID})}}{\mathrm{d}t} = \mathbf{v}^{(\mathrm{CID})} \qquad M^{(\mathrm{CID})}\frac{\mathrm{d}\mathbf{v}^{(\mathrm{CID})}}{\mathrm{d}t} = \sum_j \mathbf{F}_j^{(\mathrm{mag})} + \mathbf{F}_j^{(\mathrm{cfg})}$$

- Forces are converted to inertial frame before computing the CID trajectory

- Forces (i.e. thrust) are non-zero only when the magnets have reached the maximum displacement (20 mm)

Transient model of the CID® (3/3)

Coupling stationary magnetic model with equations of motion

- Rotational motion of the CID:

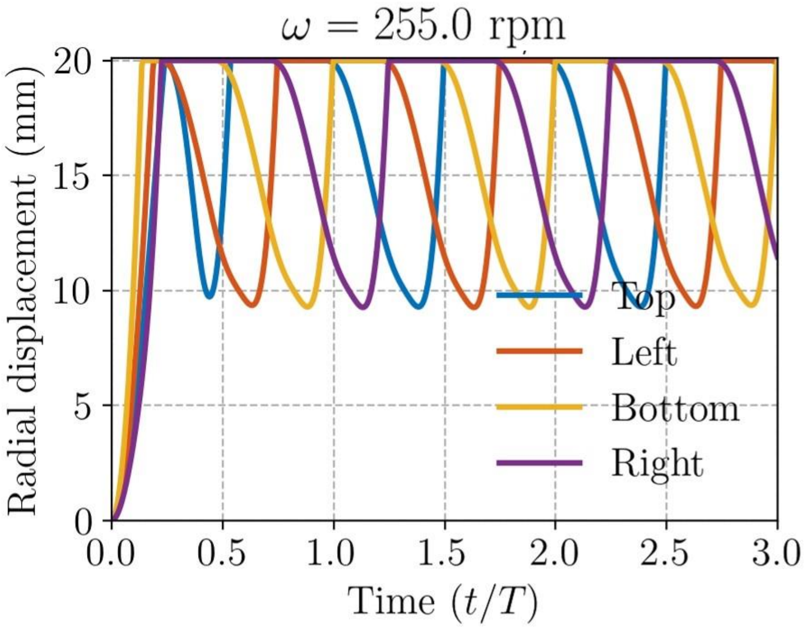
$$\frac{\mathrm{d}\theta^{(\mathrm{CID})}}{\mathrm{d}t} = \omega^{(\mathrm{CID})} \qquad I^{(\mathrm{CID})}\frac{\mathrm{d}\omega^{(\mathrm{CID})}}{\mathrm{d}t} = \sum_j \mathbf{r}_j \times \left(\mathbf{F}_j^{(\mathrm{mag})} + \mathbf{F}_j^{(\mathrm{cfg})}\right)$$

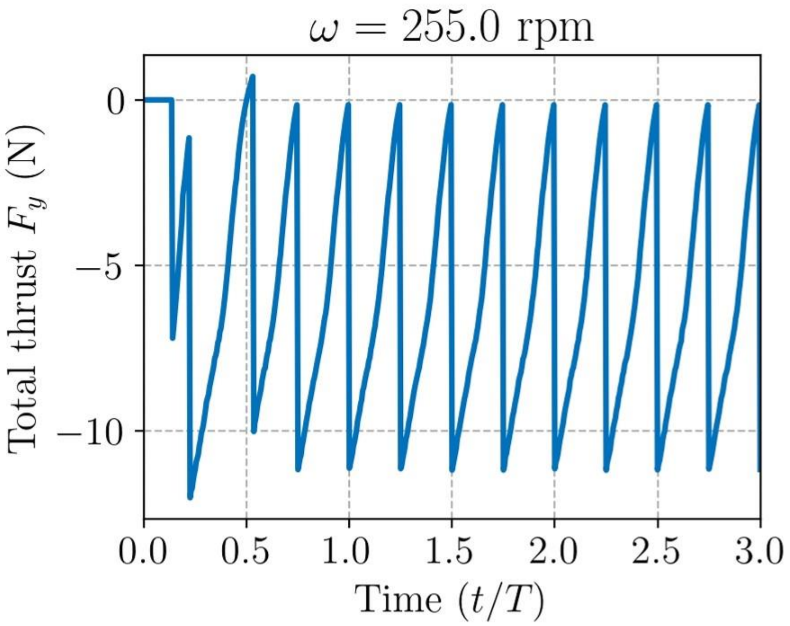
- Forces are converted to inertial frame before computing the torque on CID

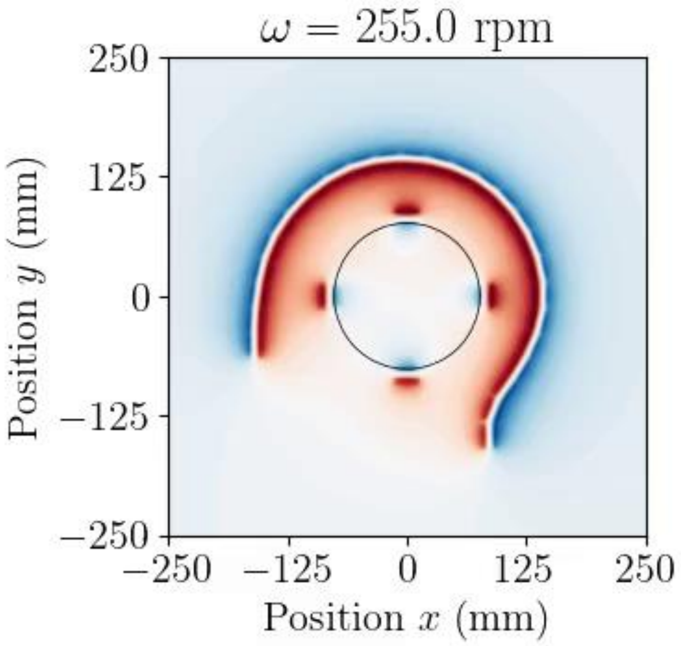
Transient model of a single ring-rotor

Continuous thrust imparted to the device

Sum of thrust forces due to all magnets in the inertial frame of refence



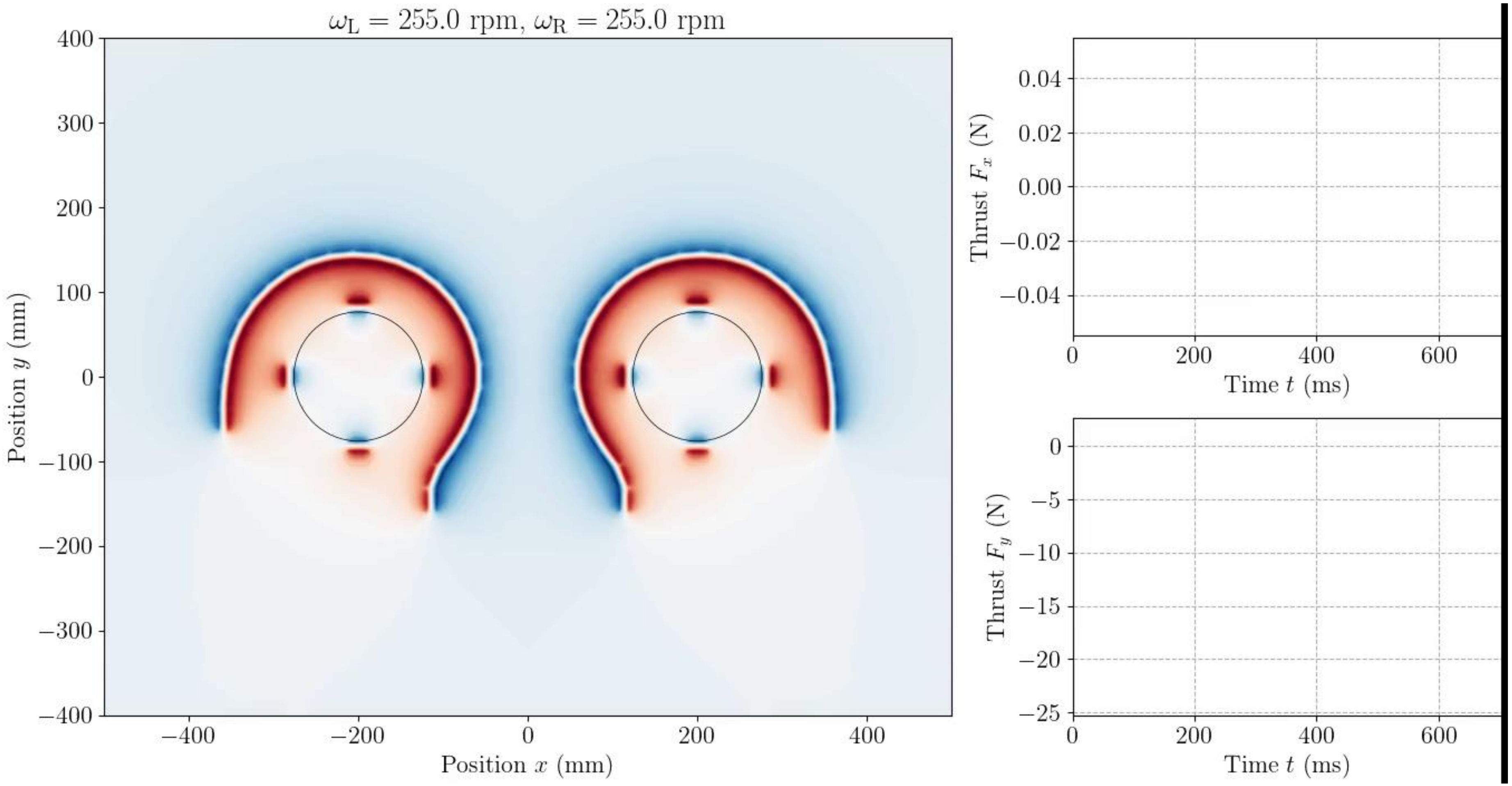




T = 0.235s is the period of one full rotation at ω = 255 rpm

CID® in linear motion

Symmetric geometry leads to only vertical motion



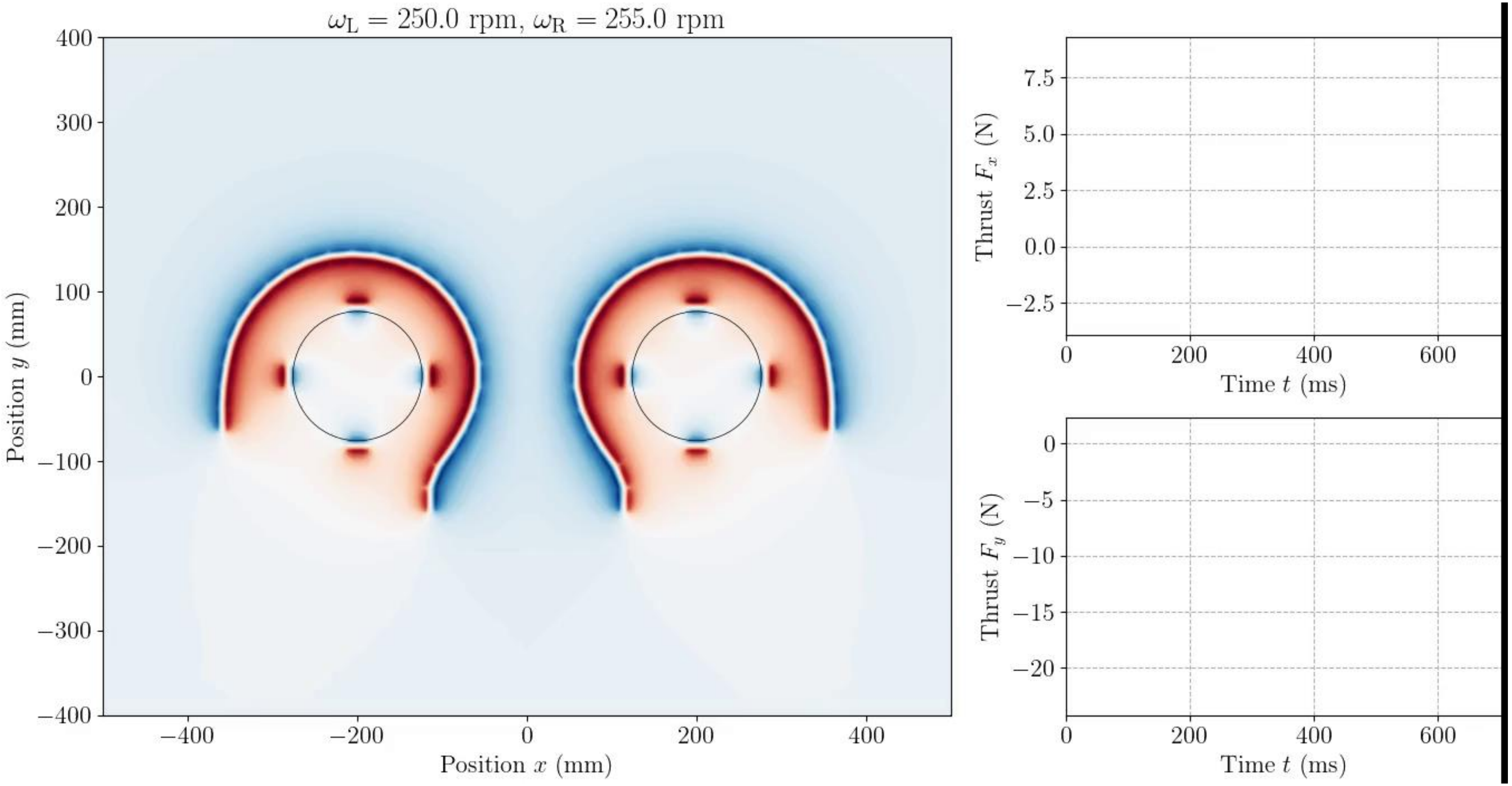
Using CID® to move a non-linear path

Introducing asymmetry to steer direction

- Horizontal forces cancel out in symmetric CID®
- Possibilities to break symmetry: geometric rotation of either magnetic ring, rotational offset or detuning the frequency of either rotor
- For demo, we introduce a small frequency detuning between the two rotors to demonstrate the CID® potential to control direction as well

CID® in non-linear motion

Frequency detuning enables directional steering



Summary

- We created a 3D electromechanical model of the CID® taking into account realistic device parameters

- The model predicts the CID® produces an average thrust of 10N

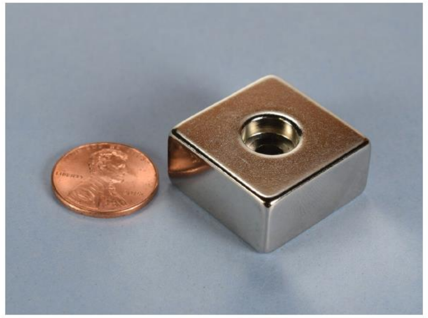
- By detuning the rotor frequency, the model also demonstrated the ability of CID® to control the direction of motion

Magnets used in the device and model

BX0X08DCB Specification Sheet

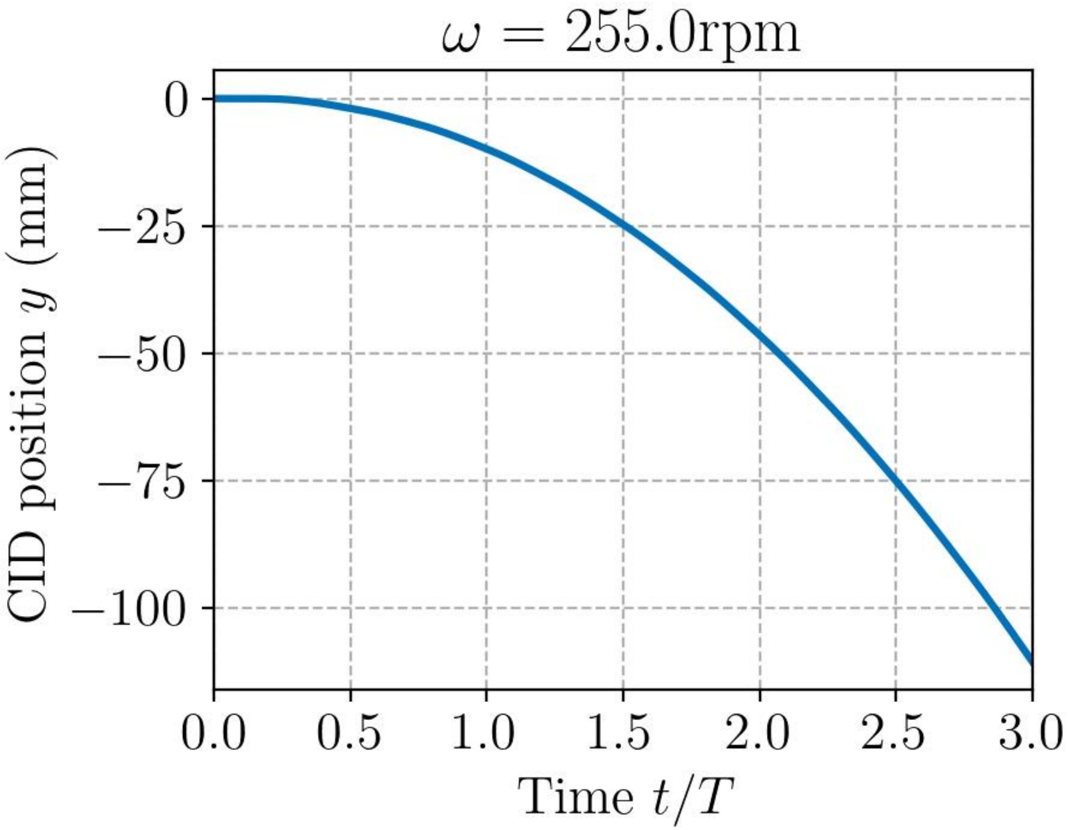
Product Specifications

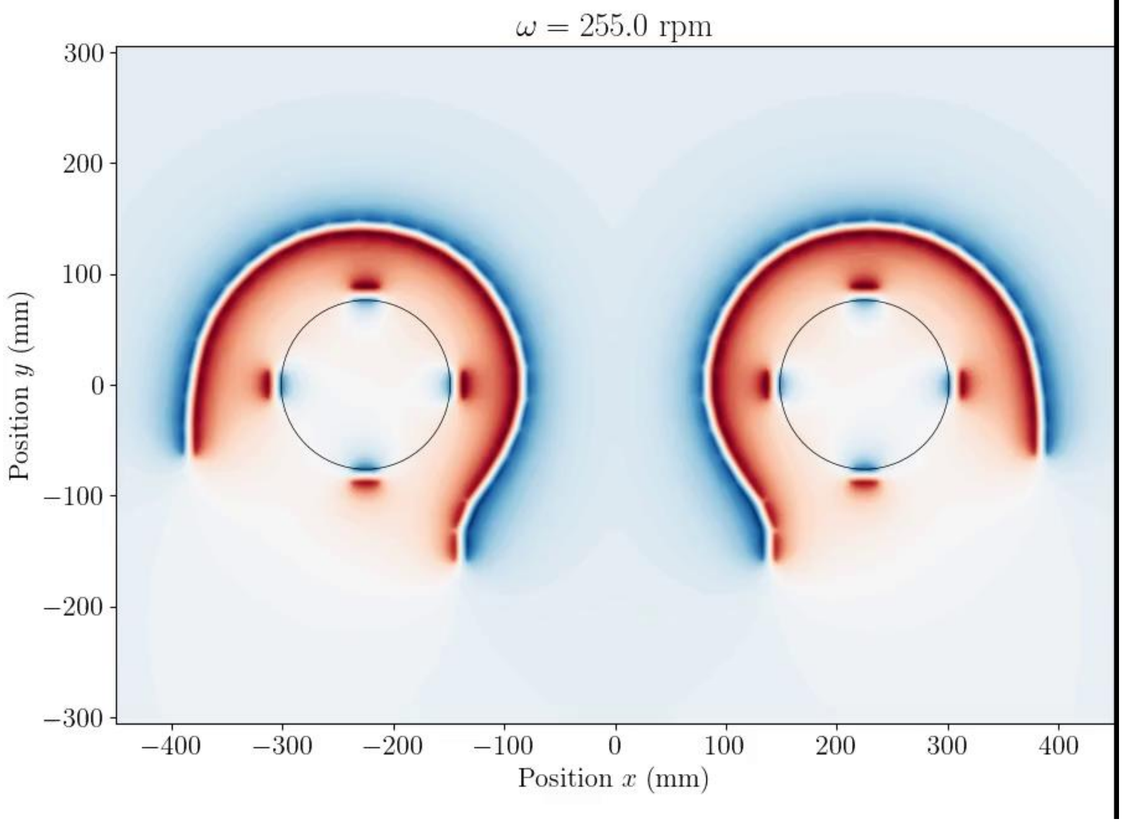
Type:	BLOCK
Dimensions:	1 x 1 x 0.5 thk (in)
Tolerance:	All dimensions ± 0.004 in
Material:	NdFeB, Grade N42
Plating:	NiCuNi
Max Op Temp:	176ºF (80ºC)
Br max:	13,200 Gauss
BH max:	42 MGOe



CID® with identical ring-rotor parts

Horizontal forces cancel out leading to linear motion

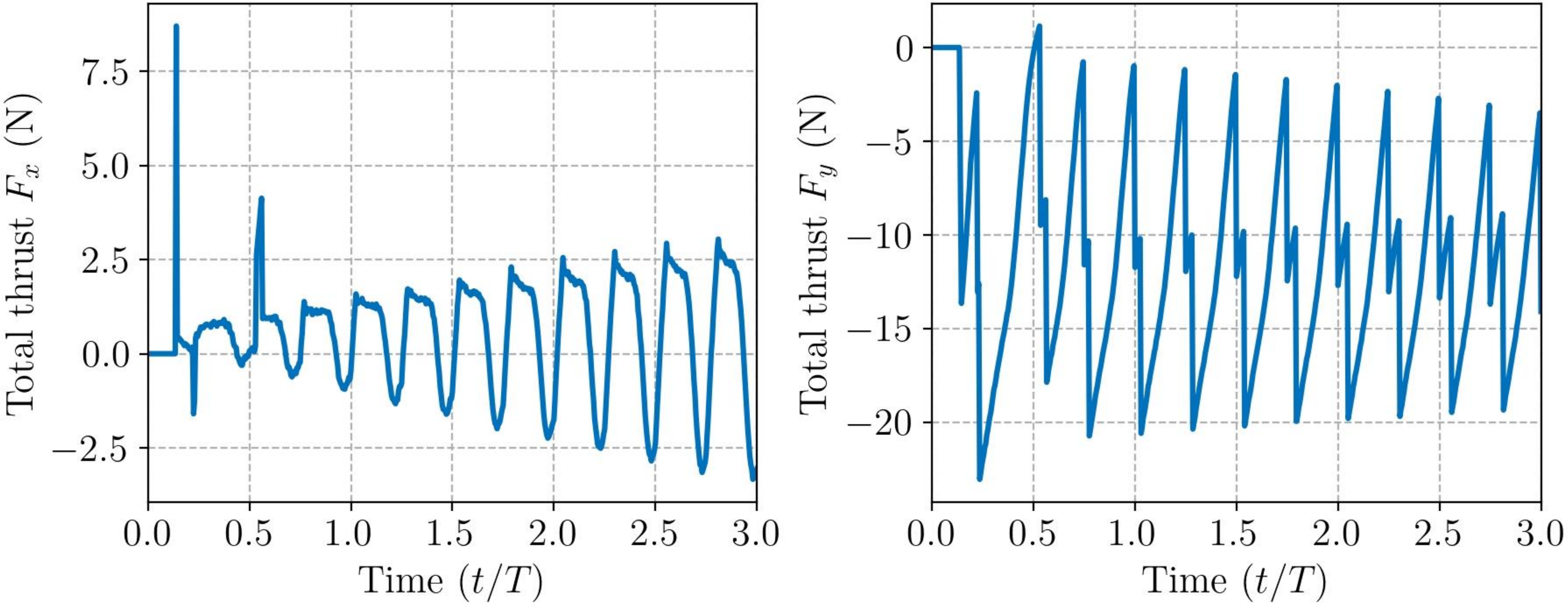




T = 0.235s is the period of one full rotation at ω = 255 rpm

Thrust on asymmetric CID®

Rotors with detuned frequencies



Motion of asymmetric CID®

Linear displacement and angular rotation