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Quantum Dynamic Enterprises Inc. Centripetal Impulse Drive Prototype Final Report – June 2019

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Research Project Objectives – Fall 2018

- **Goal:** Characterize the thrust performance of the Centripetal Impulse Drive (CID) thruster at a specific design condition

- **Objectives:**
  1. Measure the thrust of the CID over the range of operating conditions in the test matrix
  2. Capture high-resolution video of the thruster in operation

- **Deliverables:**
  1. Documentation of experimental setup and operating conditions
  2. Documentation of the experiment's results including the following performance metrics:
     a) Thrust
     b) Thrust-to-Power ratio
     c) Electrical Input Power

Overview of CID Test Campaign

- **Phase II Pre-Check conducted on Thursday, May 30th, 2019 with project Sponsor at the Dynamics and Controls Systems Laboratory (DCSL)**

  1. Final CID thruster configuration and operating conditions were approved by QDE personnel prior to performance testing on May 30th, 2019
  2. A few adjustments needed to provide longer battery life for testing and capture accurate RPM data

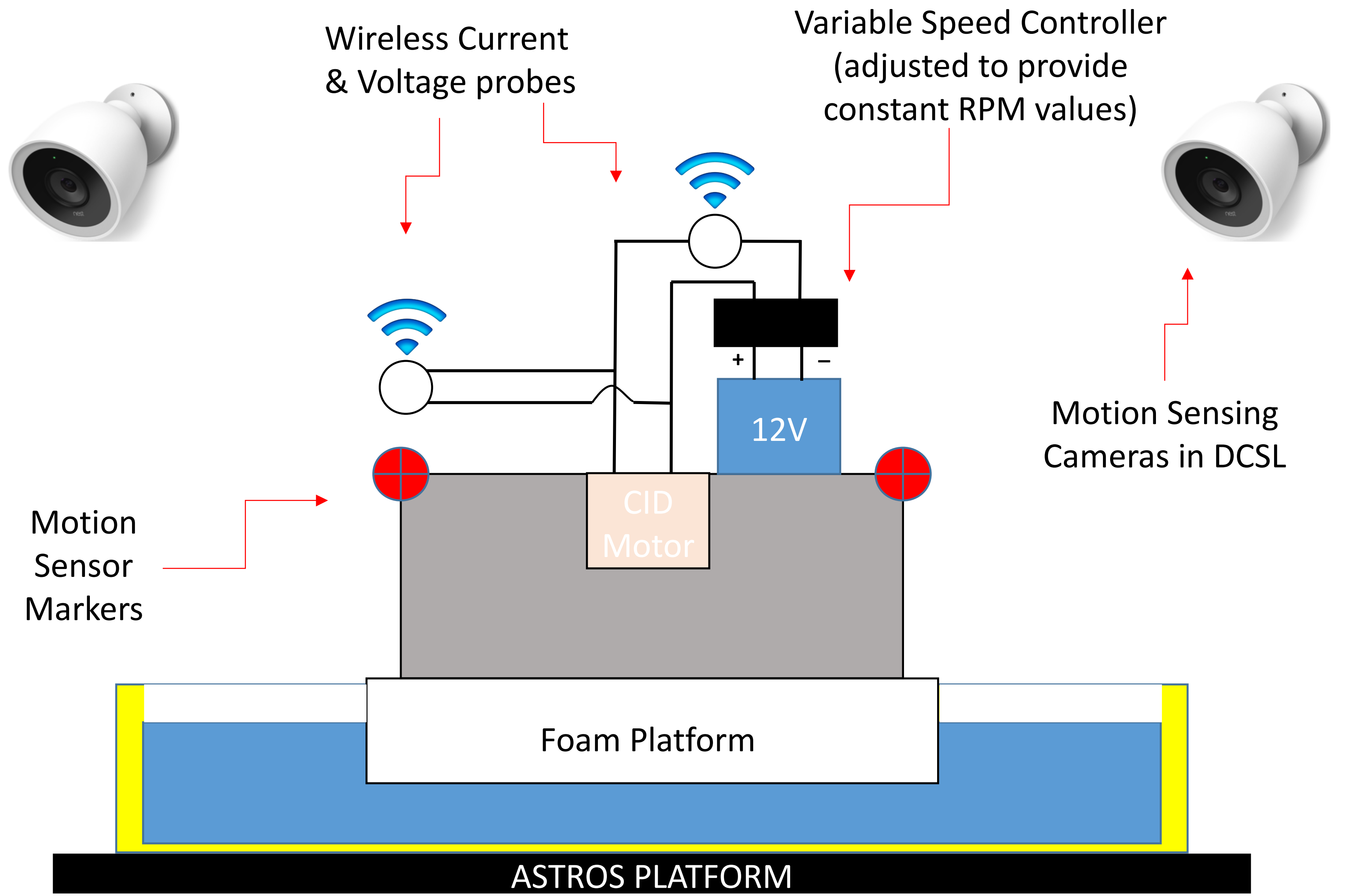
- **Final test campaign conducted on Friday, May 31st, 2019**

  1. Project sponsor was invited to witness the execution of the test operations
  2. A total of 12, three-minute trials were performed in which input power and translational motion of CID was captured
  3. Video of each trial was also captured by the project sponsor

Phase II CID Configuration and Test Plan

- Friday, 05/31/19

ConOps of CID Test Campaign

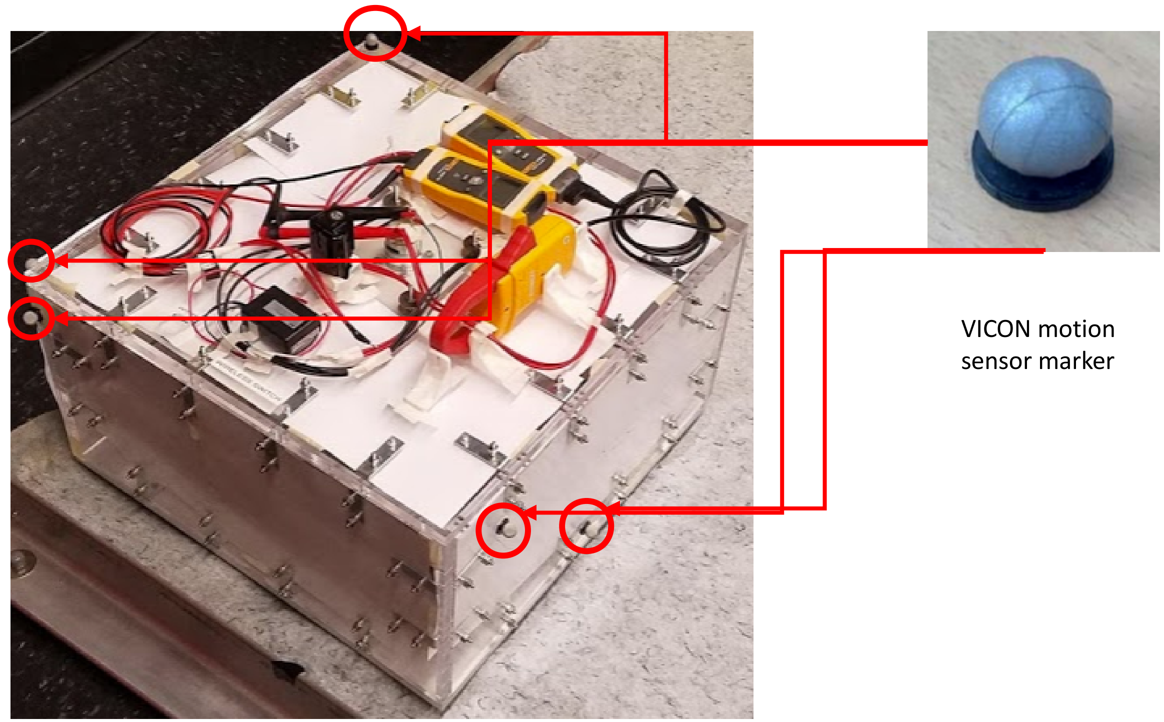


Generalized Sequence of Events

1. Perform visual inspection and check of CID hardware.
2. Setup water table in DCSL ASTROS platform.
3. CID is equipped with VICON motion sensor markers (5 total).
4. VICON software program is calibrated and the geometric center of the CID is defined.
5. Current and voltage probes are calibrated using the Fluke wireless software.
6. Water table is filled with water and final visual inspection of CID and foam platform is performed.
7. One test operator holds the CID in place, while the other test operator adjusts the RPM values to meet operational requirements
8. Once RPM value is set, test operator releases the CID
9. Test trial begins for approximately 2 - 3 minutes: DCSL personnel begin motion sensor software to capture the translation of CID, HPEPL personnel capture input current and voltage into CID motor
10. RPM data is captured periodically to verify constant value operations
11. Once trial is over, CID is switched off and data logging is completed.
12. Repeat sequences 7 and 11 over the course of several trials to obtain a performance profile over predetermined RPM values.

VICON Center of Gravity Definition

- **A total of 5 VICON markers were arbitrarily placed along three perpendicular planes defining the CID's body**



VICON motion sensor marker

1) The VICON motion sensor camera network identifies the 5 markers on the CID
2) Using the known dimensions of the CID, the geometric center of the CID is found
3) The geometric center is then referenced with respect to the center of gravity of the CID
4) Approximated as acting right in the center of the CID geometry

VICON Center of Gravity Definition

- **The geometric center is visually monitored as the CID moves during each test operation.**

- **The VICON software package employs an intermediate step to transform the position data to the Center of Gravity of the CID.**

Phase II Test Matrix

Performance Characteristic	Data Type					
	Time	Voltage	Current	Position	Attitude	RPM
Input Power	X	X	X			
Acceleration	X			X	X	
Rotor Spin (RPM)	X					X

Trial	Input Power	Acceleration	Rotor Spin (RPM)	Date	Duration (min)	Filename
1	X	X	240	5/31/19	2:43	Walker_Thrust_Test20190531T110137.mat
2		X	N/A	5/31/19	N/A	Walker_Thrust_Test20190531T111435.mat
3	X	X	240	5/31/19	6:48	Walker_Thrust_Test20190531T113044.mat
4	X	X	242	5/31/19	7:19	Walker_Thrust_Test20190531T120225.mat
5	X	X	238	5/31/19	3:23	Walker_Thrust_Test20190531T122746.mat
6	X	X	240	5/31/19	4:05	Walker_Thrust_Test20190531T123935.mat
7	X	X	240	5/31/19	2:33	Walker_Thrust_Test20190531T144046.mat
8	X	X	235	5/31/19	3:06	Walker_Thrust_Test20190531T144814.mat
9	X	X	238	5/31/19	4:33	Walker_Thrust_Test20190531T150131.mat
10	X	X	238	5/31/19	2:45	Walker_Thrust_Test20190531T151059.mat
11			N/A	5/31/19	N/A	Walker_Thrust_Test20190531T152925.mat
12	X	X	240	5/31/19	3:56	Walker_Thrust_Test20190531T155103.mat

Data Analysis

Data Analysis Summary

HPEPL High-Power Electric Propulsion Laboratory

- **Power Input**
  1. Product of the input voltage and current: $P_{input} = V \times I$
  2. Wireless voltage and current probes used to measure the CID rotor input power

- **Acceleration/Thrust**
  1. VICON dataset consists of an 11 x N array with X-Y-Z position data with respect to the laboratory reference frame
  2. 100 data samples for CID position are collected per second (sampling frequency = 100 Hz)

11x25642 double

		4795	4796	4797	4798	4799	4800	4801
Time (sec)	1	47.7751	47.7850	47.7951	47.8044	47.8147	47.8245	47.8348
	2	0.6315	0.6315	0.6316	0.6316	0.6315	0.6313	0.6313
	3	0.0063	0.0066	0.0065	0.0066	0.0065	0.0065	0.0066
	4	0.0142	0.0142	0.0143	0.0143	0.0142	0.0141	0.0142
	5	-0.7752	-0.7752	-0.7751	-0.7752	-0.7753	-0.7754	-0.7754
	6	-0.0140	-0.0137	-0.0140	-0.0139	-0.0137	-0.0136	-0.0137
	7	0.0277	0.0281	0.0282	0.0283	0.0280	0.0279	0.0281
	8	-1.7747	-1.7747	-1.7744	-1.7744	-1.7747	-1.7752	-1.7752
X-Coordinate (m)	9	0.6281	0.6282	0.6282	0.6282	0.6282	0.6283	0.6283
Y-Coordinate (m)	10	0.8666	0.8665	0.8665	0.8664	0.8665	0.8666	0.8666
Z-Coordinate (m)	11	-0.3259	-0.3260	-0.3258	-0.3259	-0.3259	-0.3259	-0.3259

VICON dataset example

Data Analysis Summary

- 3. Thrust is calculated by first determining the acceleration in each X-Y-Z direction, which is approximated by numerically differentiating the position coordinate over the sampling time interval of 0.01 seconds. So for the acceleration in the x-direction we have:

$$a_x = \frac{dV_x}{dt} \approx \frac{\Delta V_x}{\Delta t} = \frac{\left(V_x(t_{i+1}) - V_x(t_i)\right)}{t_{i+1} - t_i}, \qquad where \quad V_x \approx \frac{\Delta x}{\Delta t} = \frac{(x(t_{i+1}) - x(t_i))}{t_{i+1} - t_i}$$

4. Using this acceleration data, we can compute Thrust in each dimension via the following equation, which, through the VICON system, is given in the *Inertial Frame of Reference (IF)*

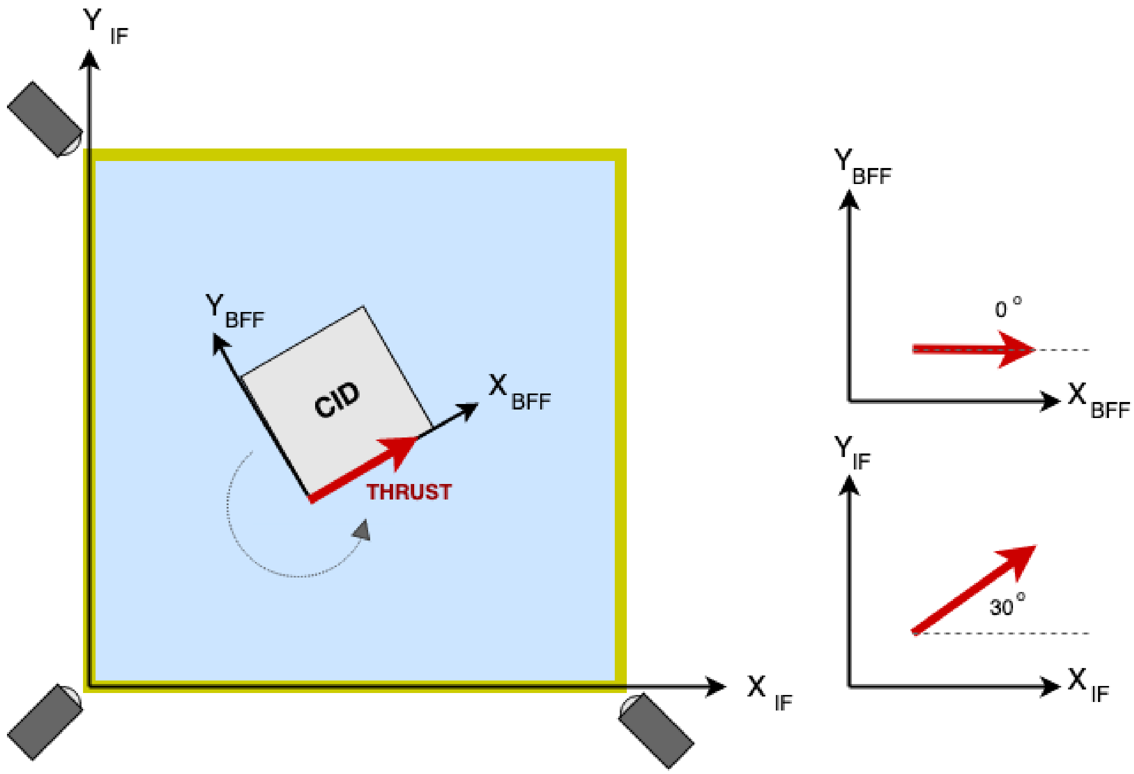
$$\text{Thrust}_{\text{Nx}} = F_{Nx} = m * a_x$$

$$\text{Thrust}_{\text{Ny}} = F_{Ny} = m * a_y$$

$$\text{Thrust}_{\text{Nz}} = F_{Nz} = m * a_z \approx 0$$

Data Analysis Summary

5. The CID rotated about its Center of Mass throughout each of the trials. From an external frame of reference, this would cause the thrust direction to appear to be rotating as well. To compensate for this rotation, we determine the thrust vector produced by the CID in the *Body-Fixed Frame of Reference*, rather than the *Inertial Frame* it was measured from.



Here we consider a scenario where the CID, the *Body-Fixed Frame*, has rotated 30o in the VICON *Inertial Frame (IF)* during operation.
As a result, when viewed from the *Inertial Frame*, the thrust appears to be applying on the CID at a different angle that it actually is. We must correct this affect by representing thrust in the Body-Fixed Frame.

Data Analysis Summary

In mathematics, the quaternions are a number system frequently used to define orientation and mechanics in 3-dimensional space. We can convert from one frame of reference to another by means of quaternion multiplication with the Unit Quaternion Rotation Matrix, Q(**q**)

The Unit Quaternion Rotation Matrix, and its conjugate, are composed of vector components *q0* through *q3* , which each relate to rotation about an axis . These components are all tracked by the VICON system to allow the user to transform from the Inertial Frame to the Body-Fixed Frame.

$$Q(\mathbf{q}) = \begin{bmatrix} q_0 & -q_1 & -q_2 & -q_3 \\ q_1 & q_0 & q_3 & -q_2 \\ q_2 & -q_3 & q_0 & q_1 \\ q_3 & q_2 & -q_1 & q_0 \end{bmatrix} \qquad \bar{Q}(\mathbf{q}) = \begin{bmatrix} q_0 & -q_1 & -q_2 & -q_3 \\ q_1 & q_0 & -q_3 & q_2 \\ q_2 & q_3 & q_0 & -q_1 \\ q_3 & -q_2 & q_1 & q_0 \end{bmatrix}$$

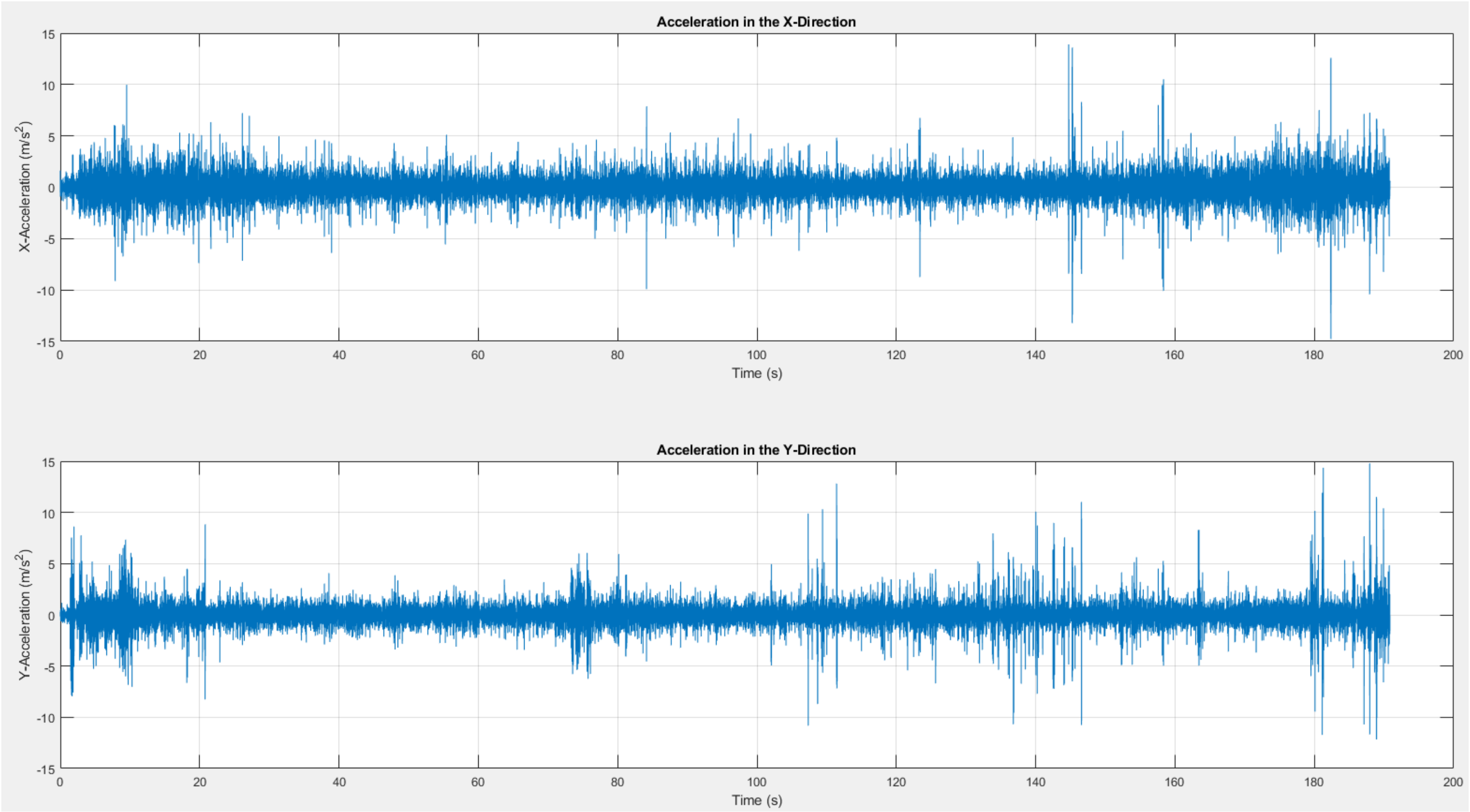
- Having composed our Unit Quaternion Rotation Matrix and its conjugate, we multiply them by the Thrust values in the *Inertial Frame of Reference* to compute them for the *Body-Fixed Frame of Reference*:

$$\begin{bmatrix} 0 \\ Thrust_B \end{bmatrix} = \bar{Q}(q)^T \, Q(q) \begin{bmatrix} 0 \\ Thrust_N \end{bmatrix}$$

6. The magnitude of the thrust is calculated as defined below. Note that because the CID motion is predominantly two-dimensional along the XY-plane, the acceleration (and therefore thrust) in the z-axis is approximately zero and the thrust presented in this report is approximated as:

$$|\overline{T_B}| = \sqrt{{T_B}_x^{\,2} + {T_B}_y^{\,2} + {T_B}_z^{\,2}} \qquad |\overline{T_B}| \approx \sqrt{{T_B}_x^{\,2} + {T_B}_y^{\,2}}$$

7. The numerically differentiated data was noisy and two filtering techniques were employed to smoothen out the data. Below is a snapshot of the X- and Y-acceleration values for a specific test run.



Data Analysis Summary

- **Data Filtering Techniques: Two methods were employed to filter and smooth the acceleration data**

- *Savitsky-Golay Filtering*

    a) Applies a finite impulse response (FIR) smoothing filter of defined polynomial order and frame length to the displacement data.

    b) Results provided in the following slides.

Moving Average Filter

a) Consistent results for all test runs,

b) Outputs a lower mean value for the acceleration on all test runs compared to the Savitsky-Golay filter,

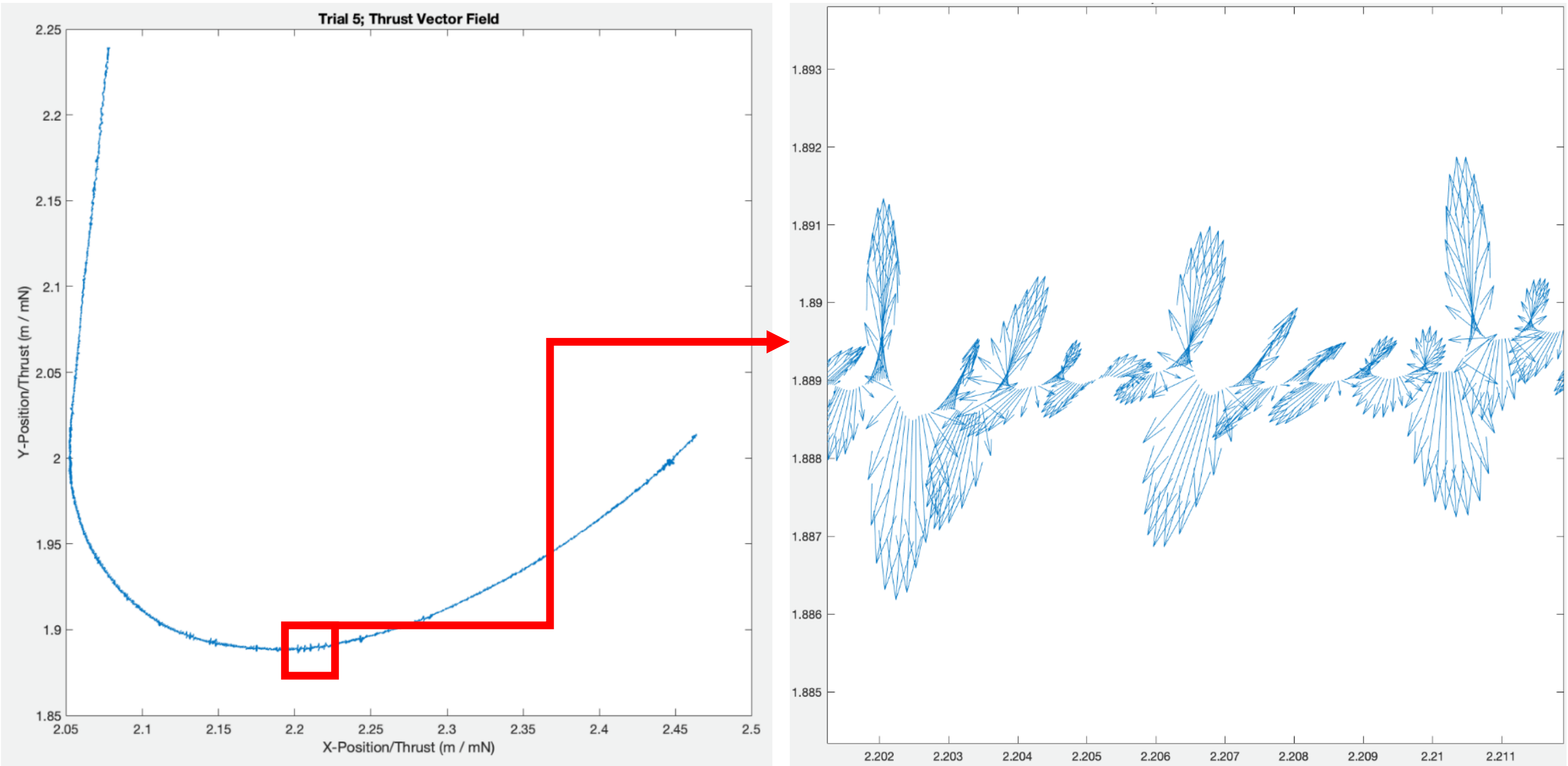
c) Governed by the following equation:

$$y_s(i) = \frac{1}{2N+1}\left(y(i+N) + y(i+N-1) + \ldots + y(i-N)\right)$$

- **Acceleration Vector field for each run**

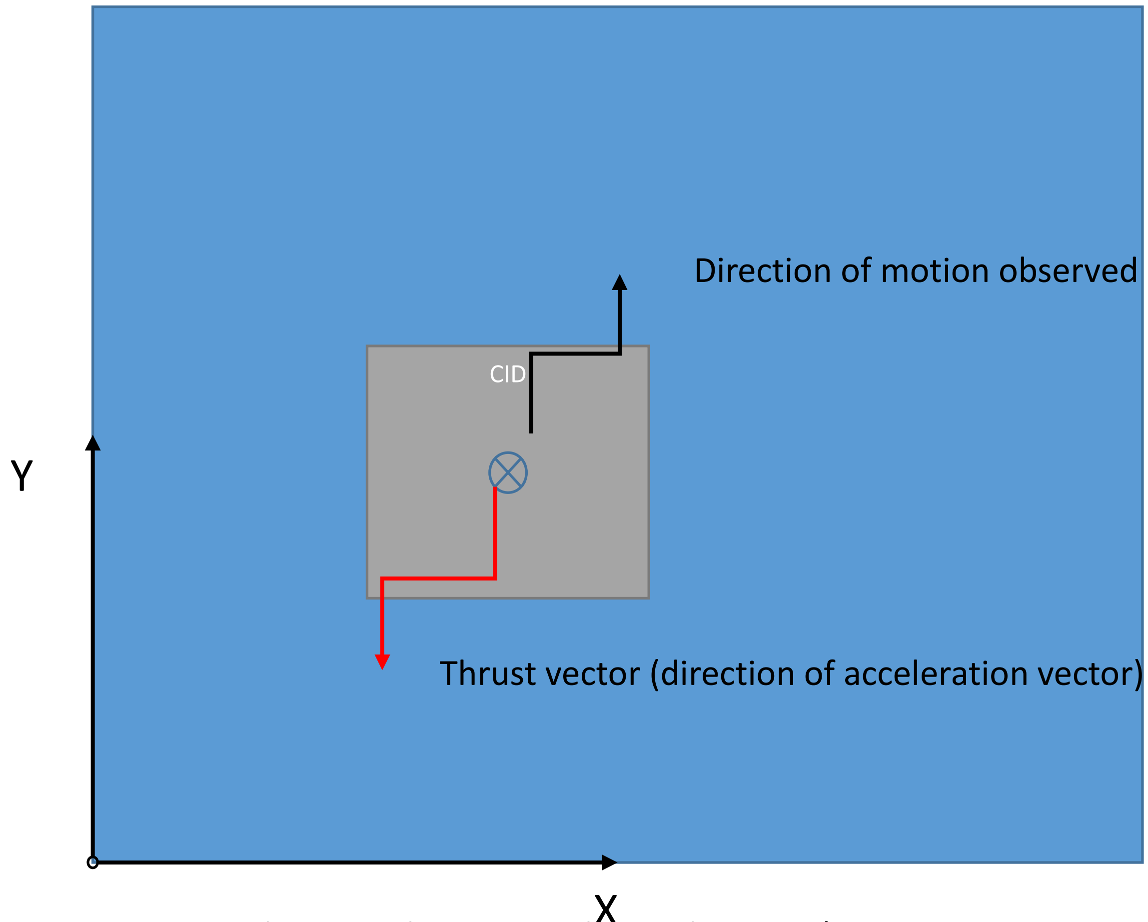
  1. *Once the X- and Y-coordinate acceleration values were calculated, it is possible to generate a vector field of the thrust vector at each CID position*

  2. *Results generally indicate that the thrust vector is constantly changing in a swirl pattern*



- **Acceleration Vector field for each run**

  1. *The thrust vector is the direction in which the CID's center of gravity accelerates linearly at a constant value around 240 RPM's*

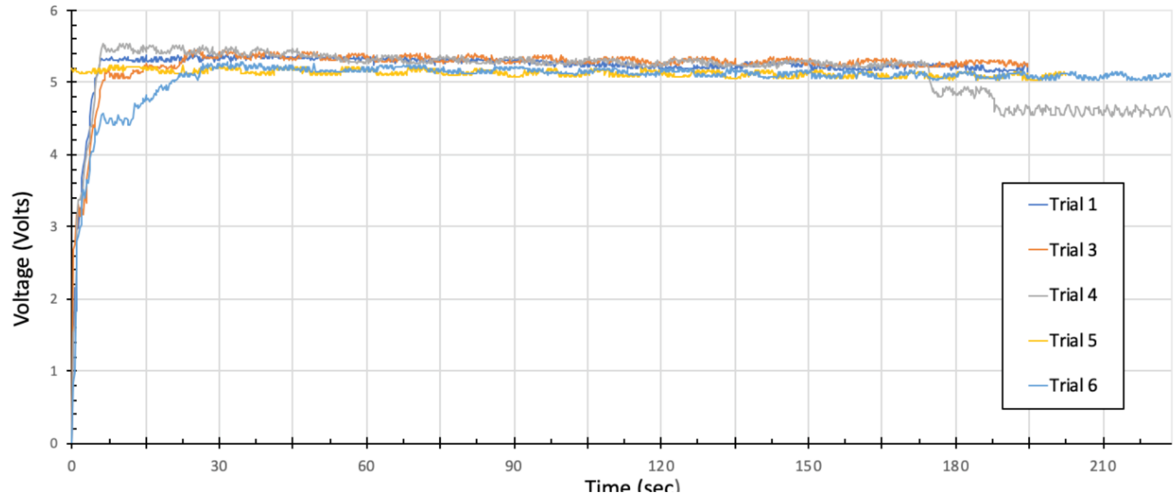


Phase II Test Results

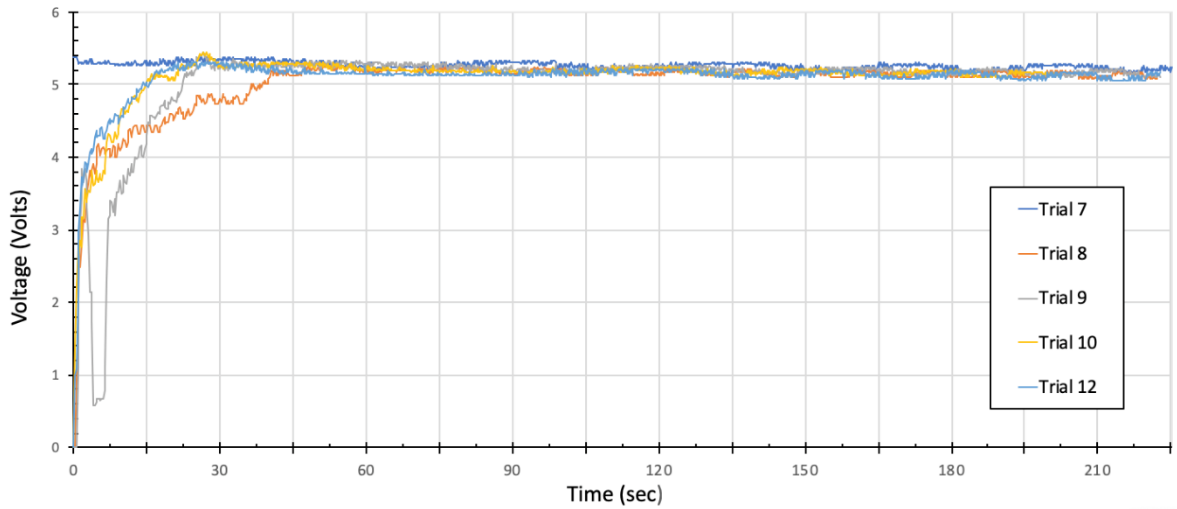
- Friday, 05/31/19

Voltage Input Summary

- Nominal voltage value of **5.19 VDC** for constant 240 RPMs
- Voltage input decreases over the course of each run.

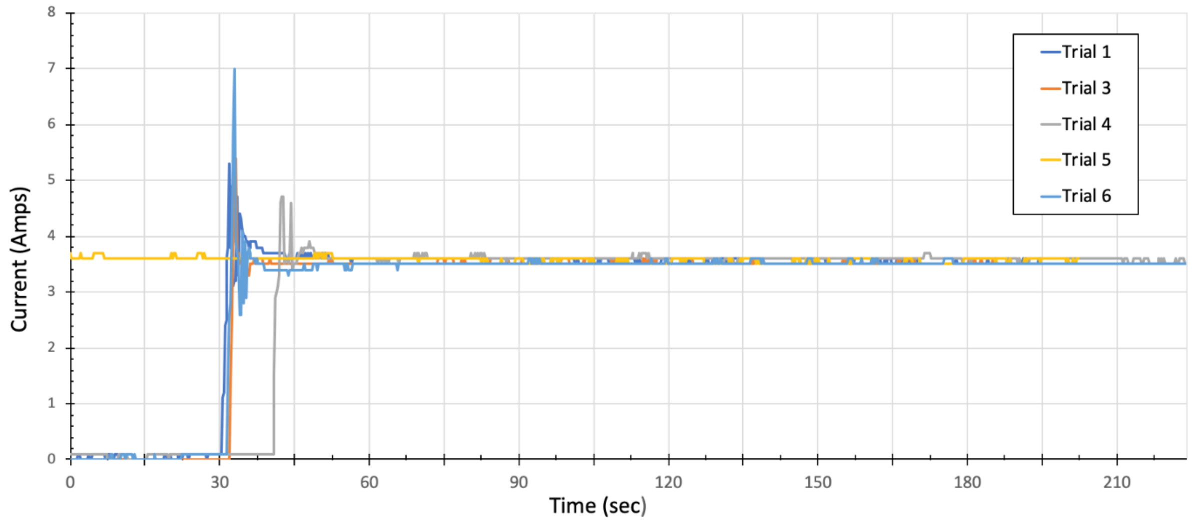


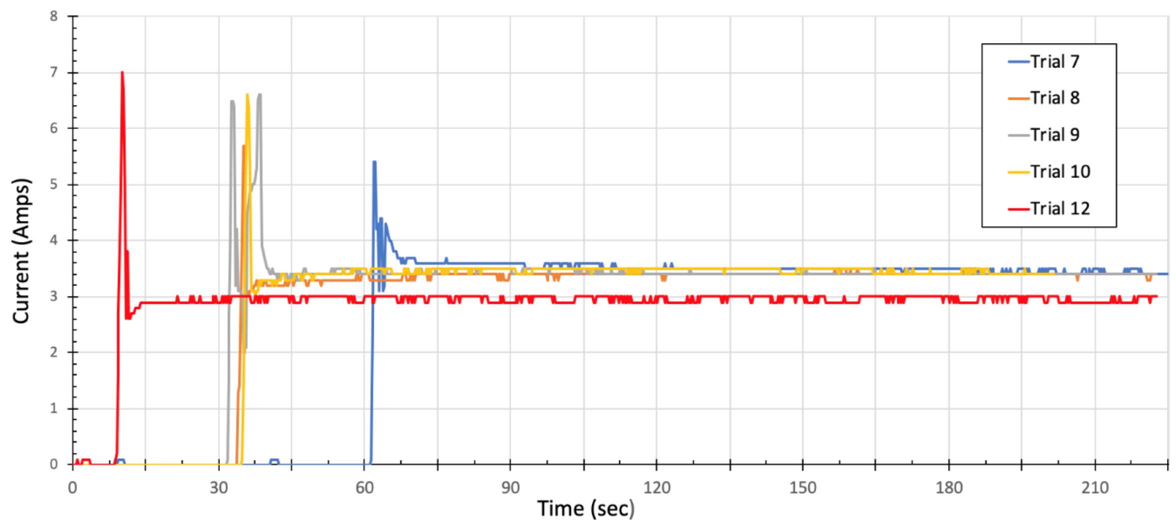
- Batteries were replaced regularly between trials to avoid meeting the minimum threshold of 8.5 VDC.
- Voltage data was not captured for trial 2 and 11 due to signal loss



Current Input Summary

- Nominal current value of **3.50 A** for constant 240 RPMs
- Current input was about constant for all test runs, with the exception of Trial 12; the CID's pistons taped down, resulting in a current output of 2.96 A.
- Overall CID demonstrated an average input current of 3.50 A every test run.





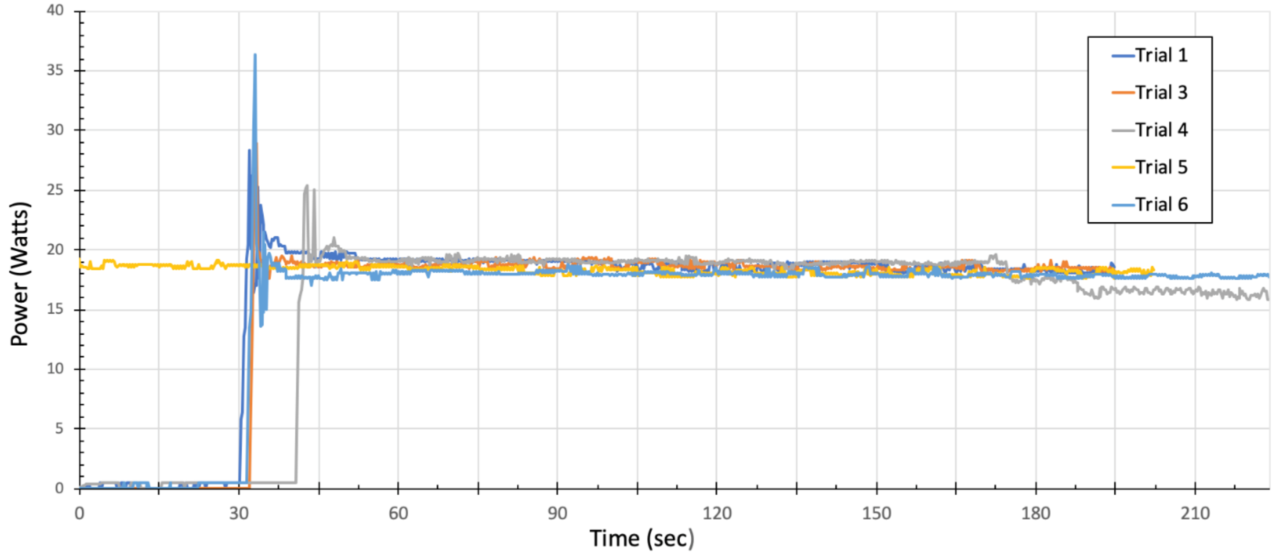
Power Input Summary

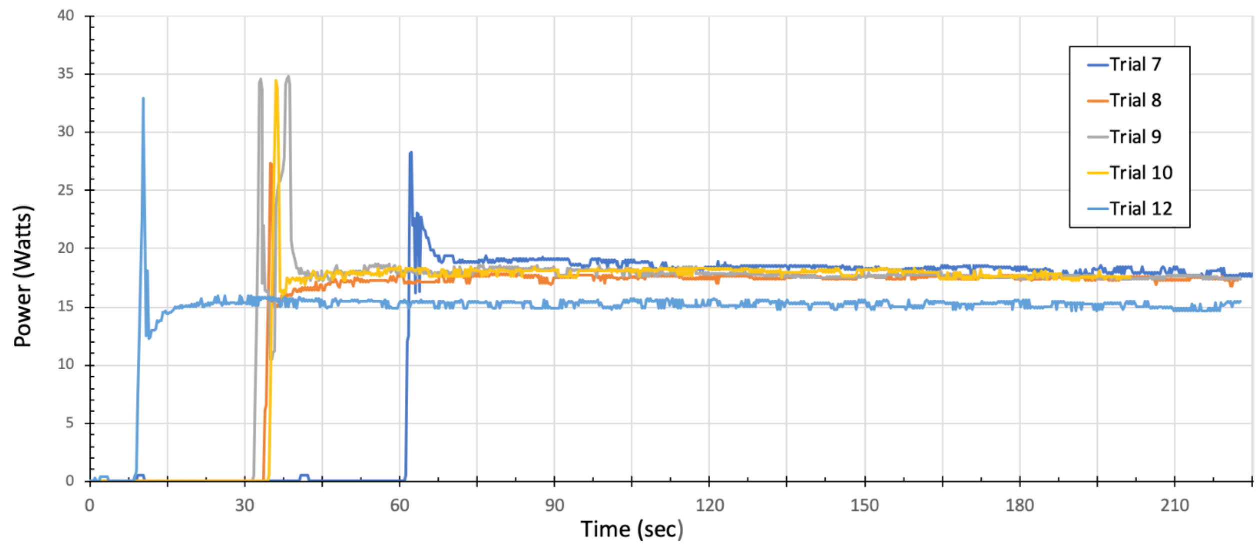
- Input power was calculated for each test run as:

  Pin = V x I

- The average input power was **18.15 Watts** under the normal conditions of 240 RPMs

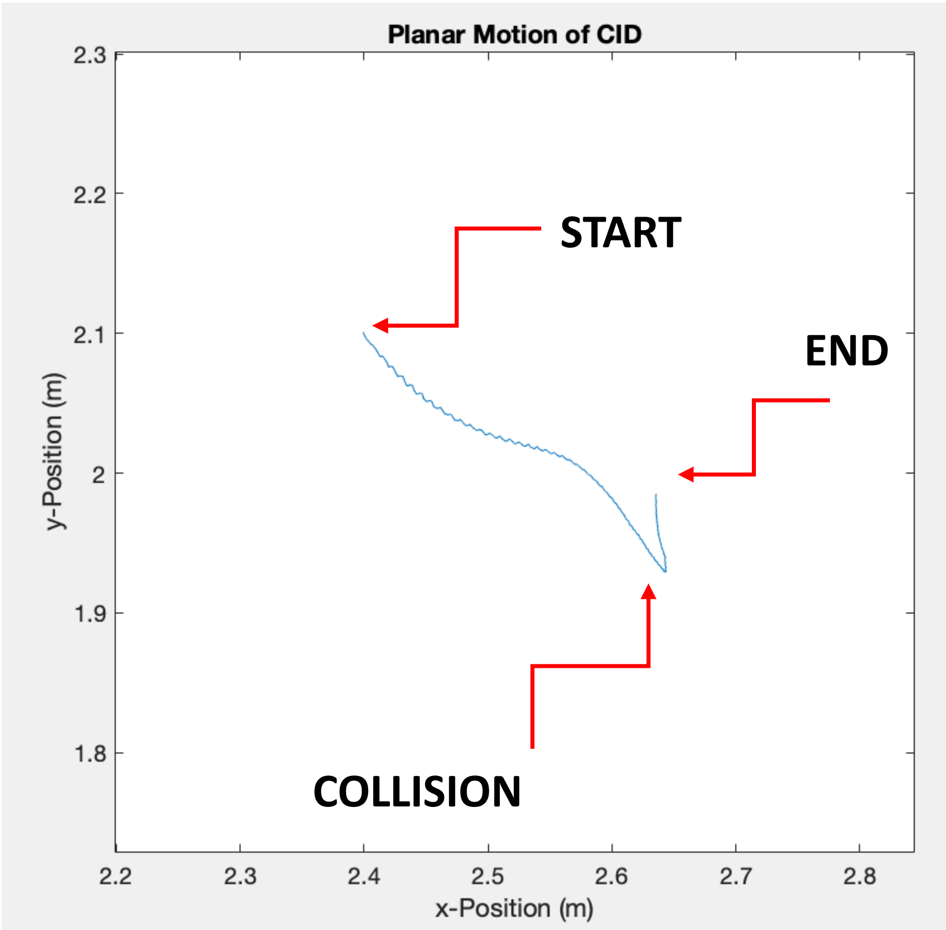
- As expected, power decreased as the voltage input decreased with each test run.

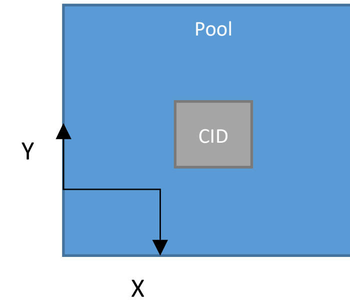




Position Summary Data

- **Trial 1** demonstrated net translational + rotational motion.





Average magnitude of Force	3.746 mN
Test Duration	2:43
Target Speed	240 RPM
Speed Range	241-236 RPM

Trial ended shortly after diagonal motion caused the CID to collide with the pool wall.

Position Summary Data

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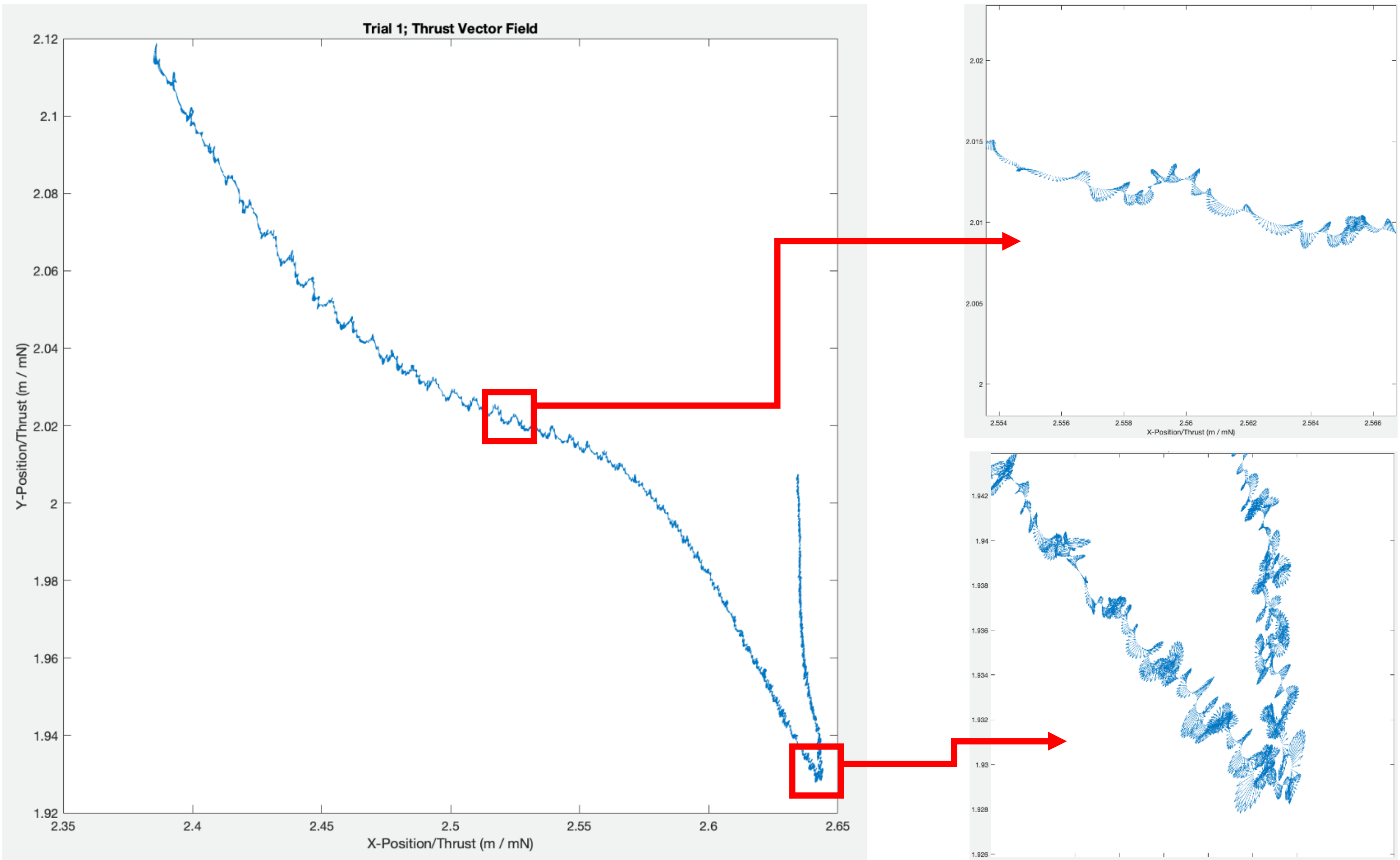
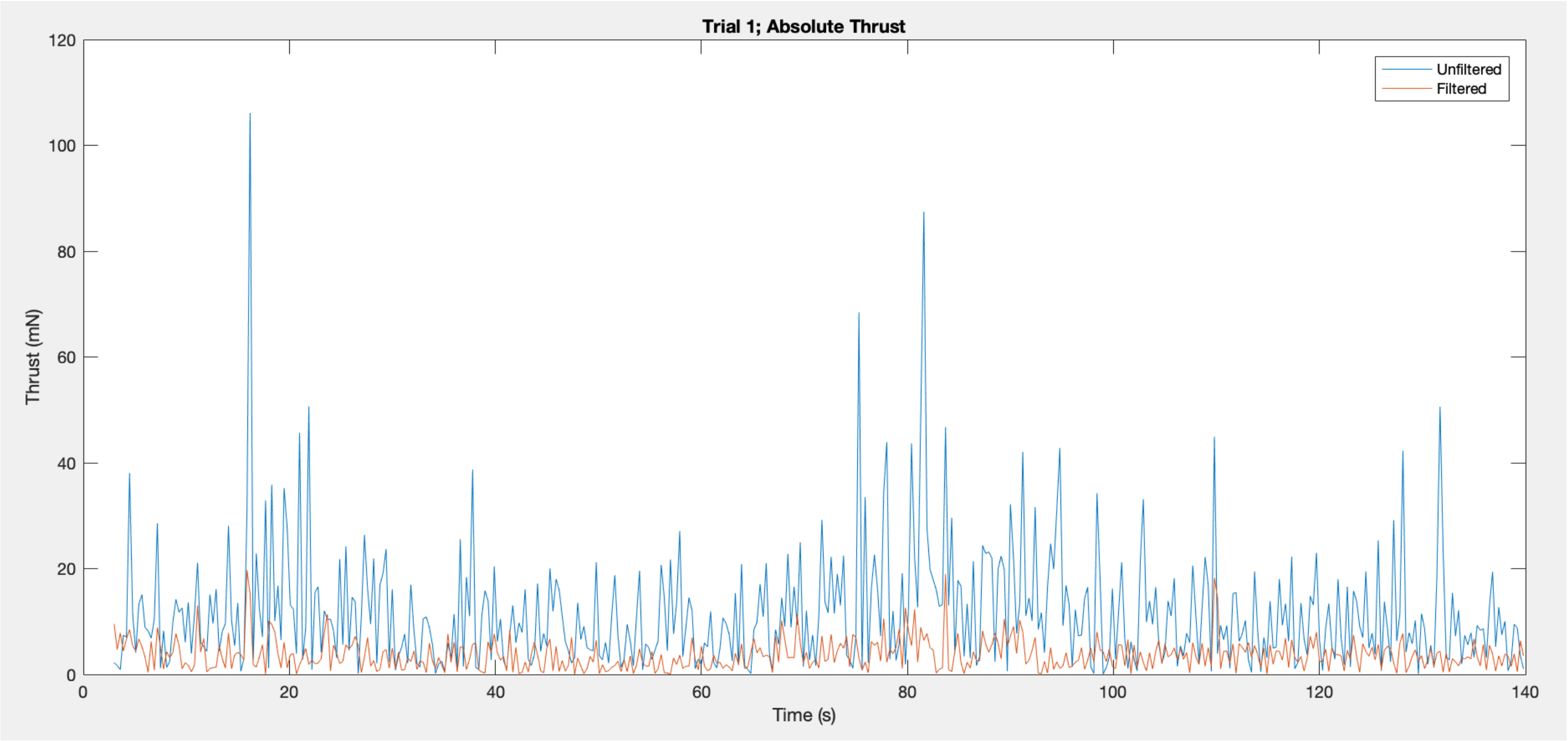
- **Trial 1 5/31/2019 10:57**

  XY position as a function of time



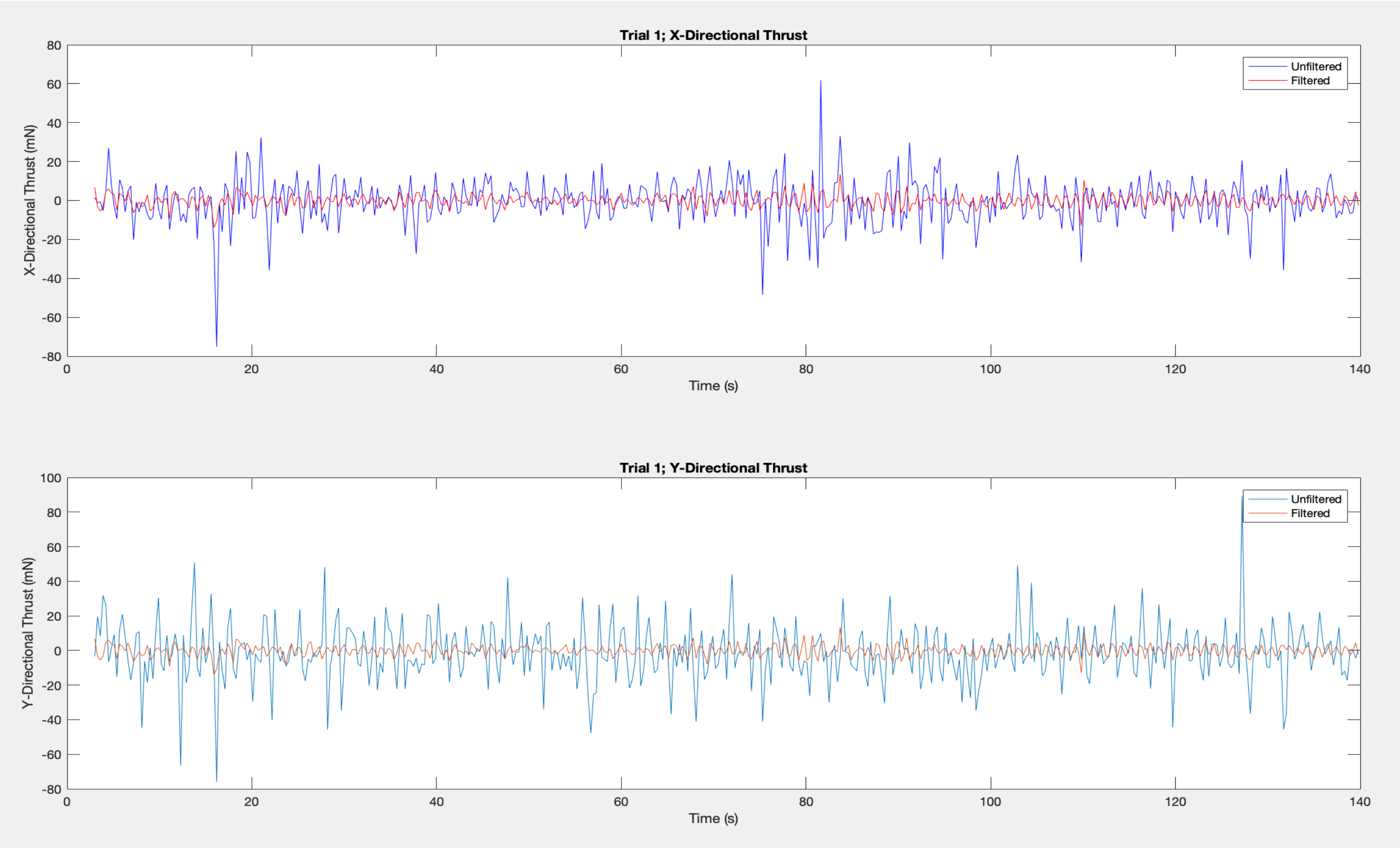
Force Summary

- **Trial 1 5/31/2019 10:57**
  1. Force value obtained: Numerical Differentiation.
  2. Plot Filtering: Moving Mean & Savitsky-Golay.
  3. **Average Magnitude of Force = 3.746 mN**



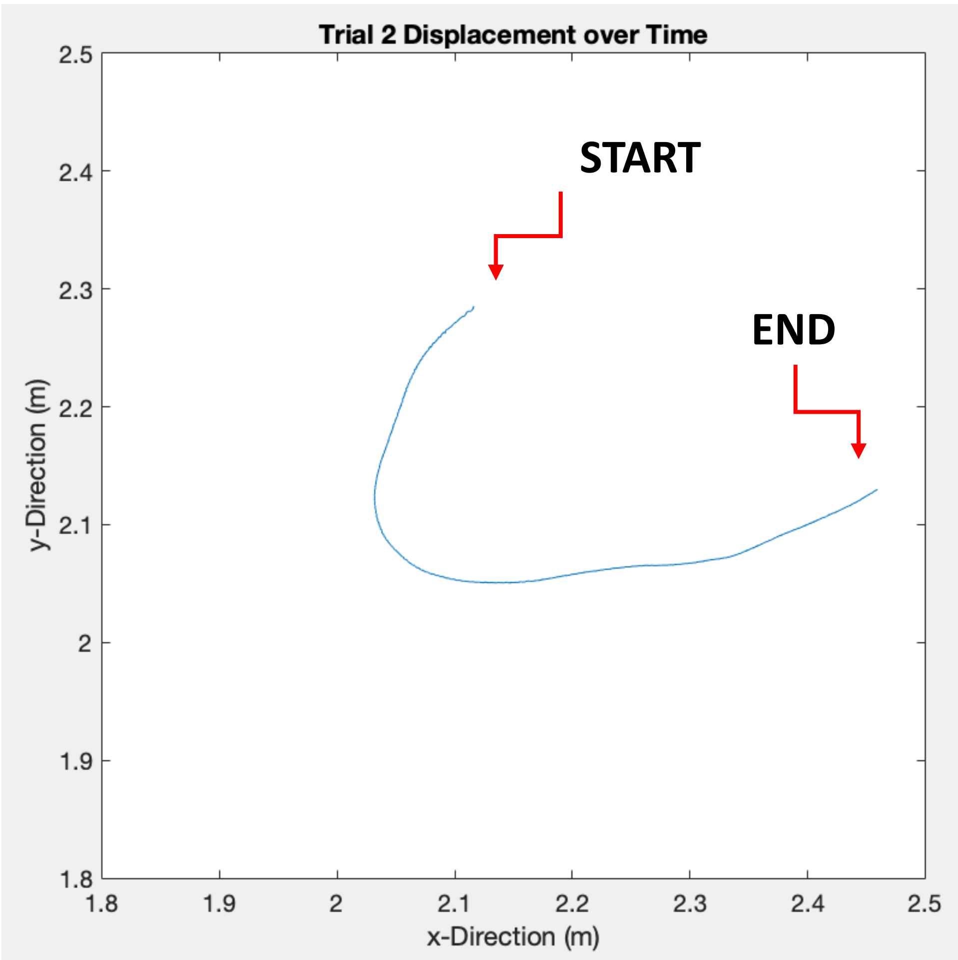
- **Trial 1 5/31/2019 10:57**

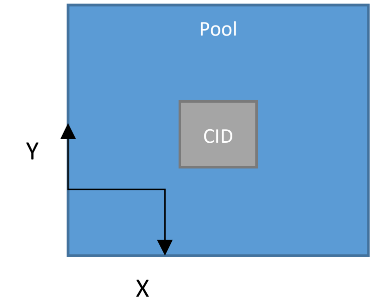
1. Force in the X and Y directions.



Position Summary Data

- **Trial 2** demonstrated net translational + rotational motion.



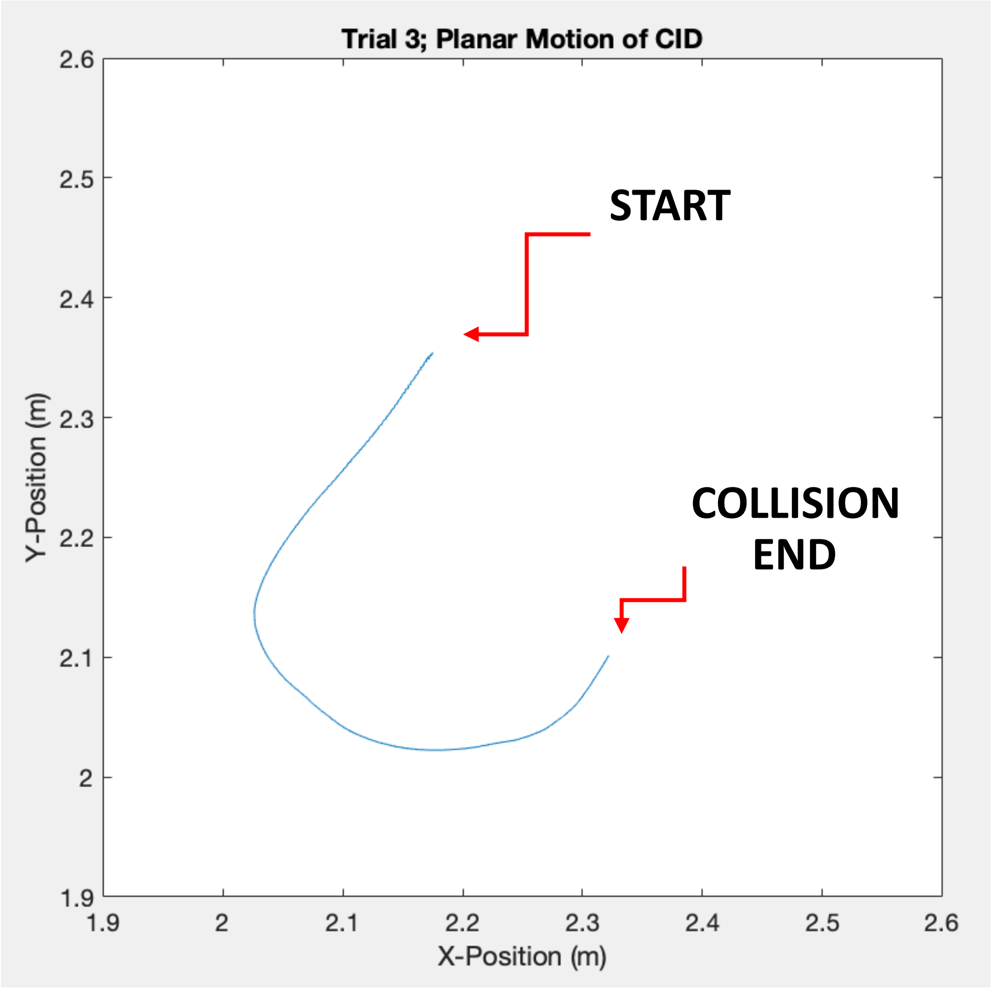


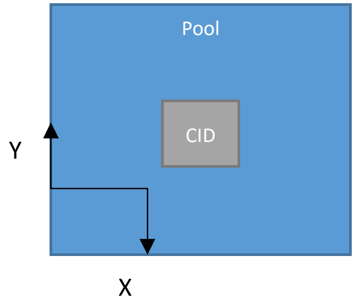
Average magnitude of Force	N/A
Test Duration	N/A
Target Speed	240 RPM
Speed Range	241-236 RPM

The wireless Voltage probe disconnected from the recording device. As a result, no data were obtained from this test.

Position Summary Data

- **Trial 3** demonstrated net translational + rotational motion.



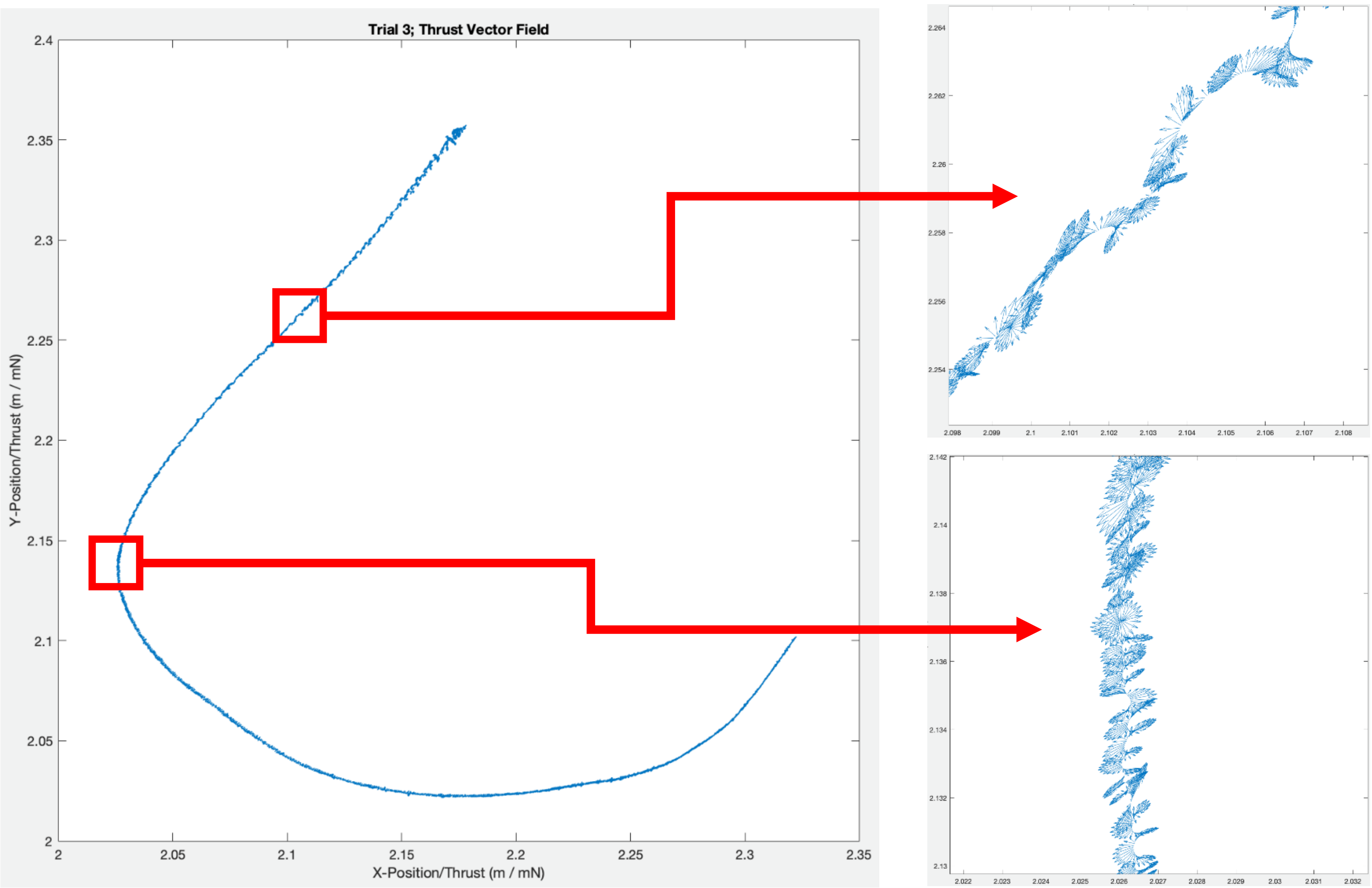


Average magnitude of Force	4.503 mN
Test Duration	6:48
Target Speed	240 RPM
Speed Range	247-237 RPM

The corner of the CID hit the pool wall, thus ending the trial.

- **Trial 3 5/31/2019 11:24**

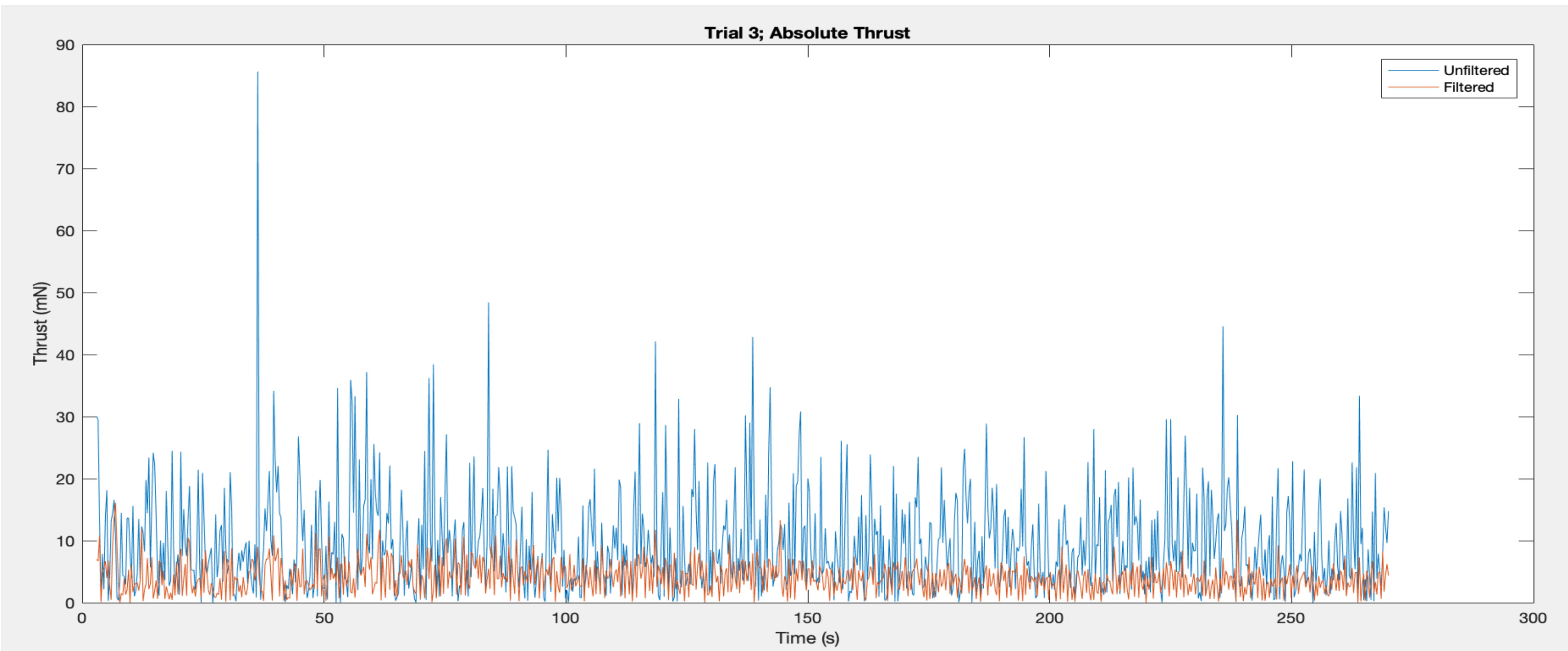
XY Position as a function of time



Force Summary

- **Trial 3 5/31/2019 11:24**

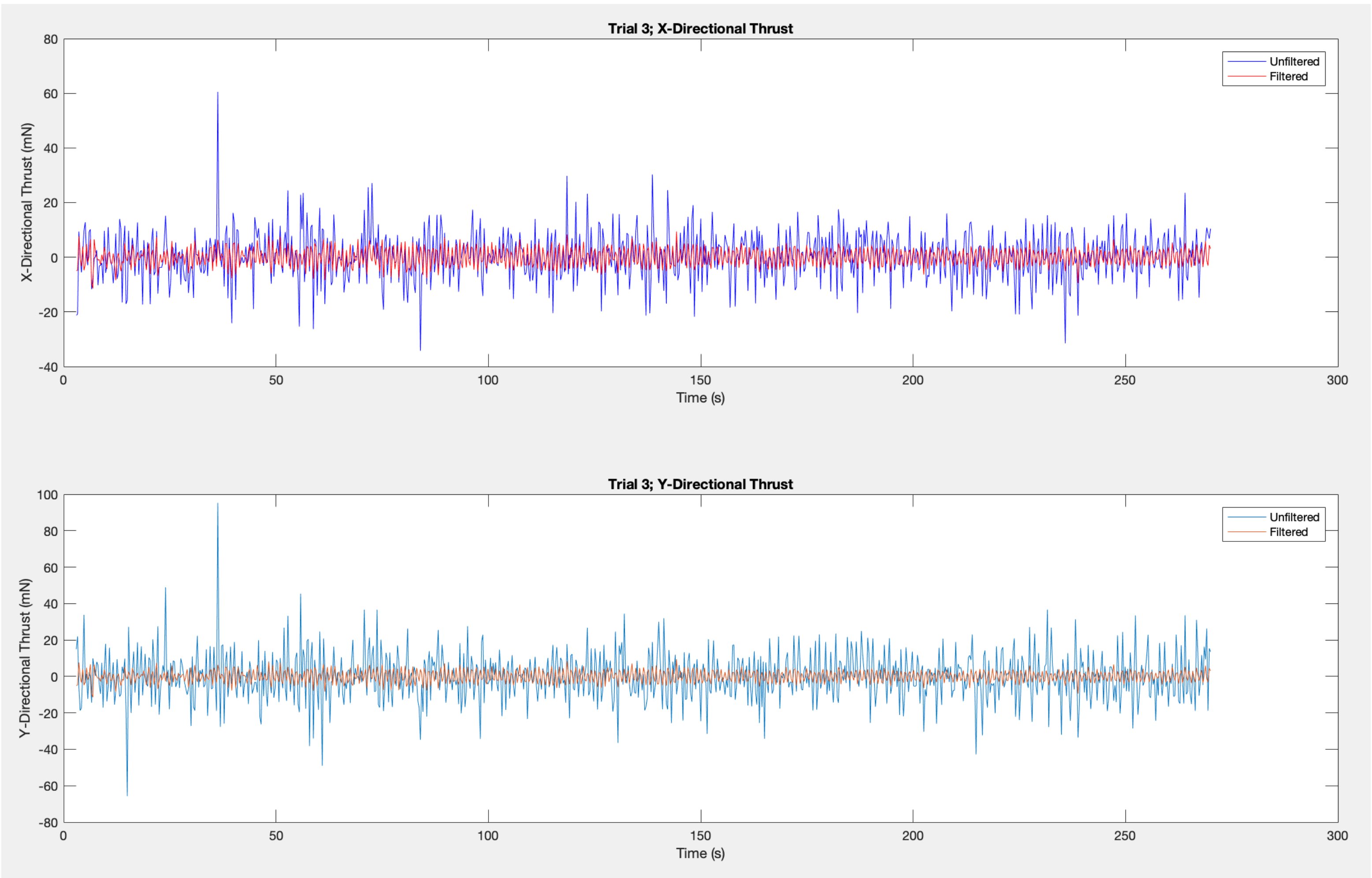
1. Force value obtained: Numerical Differentiation
2. Plot Filtering: Moving Mean & Savitsky-Golay
3. **Average Magnitude of Force = 4.503 mN**



Force Summary

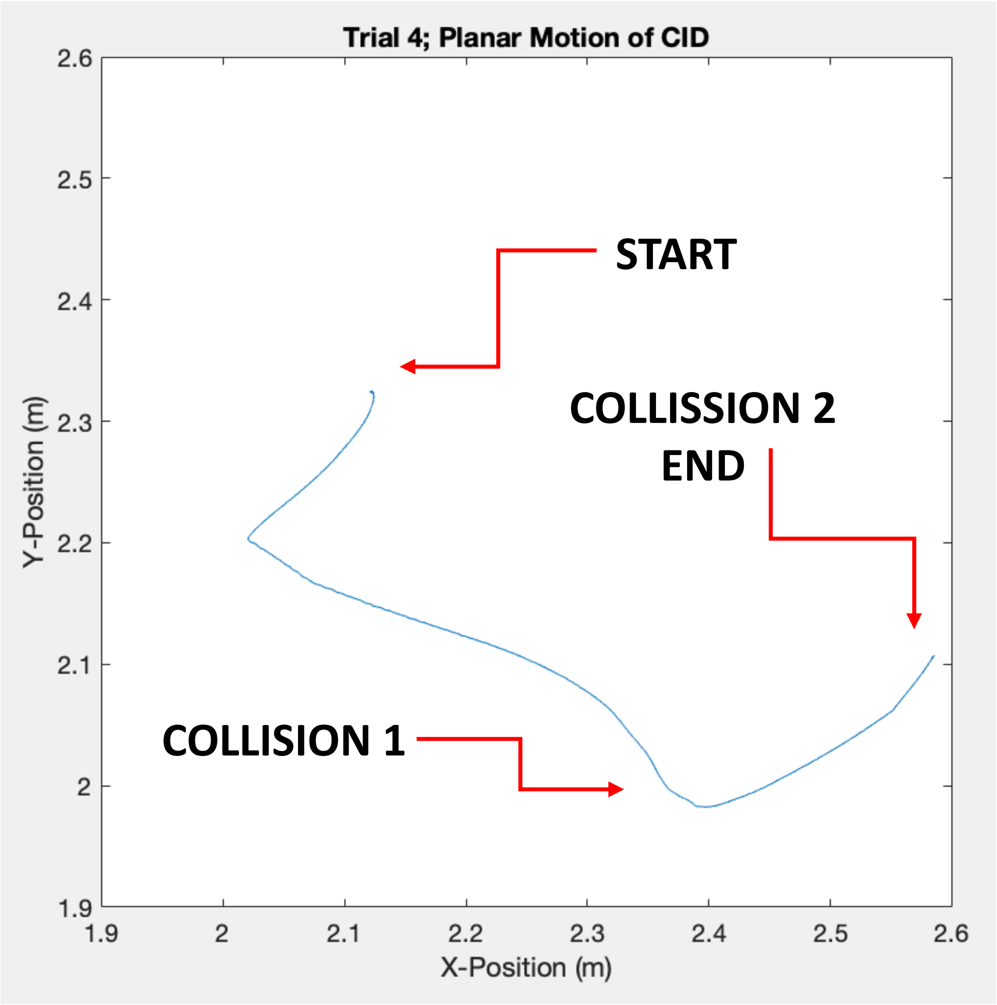
- **Trial 3   5/31/2019   11:24**

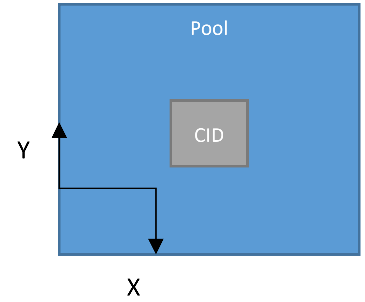
1. Force in the X and Y directions.



Position Summary Data

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





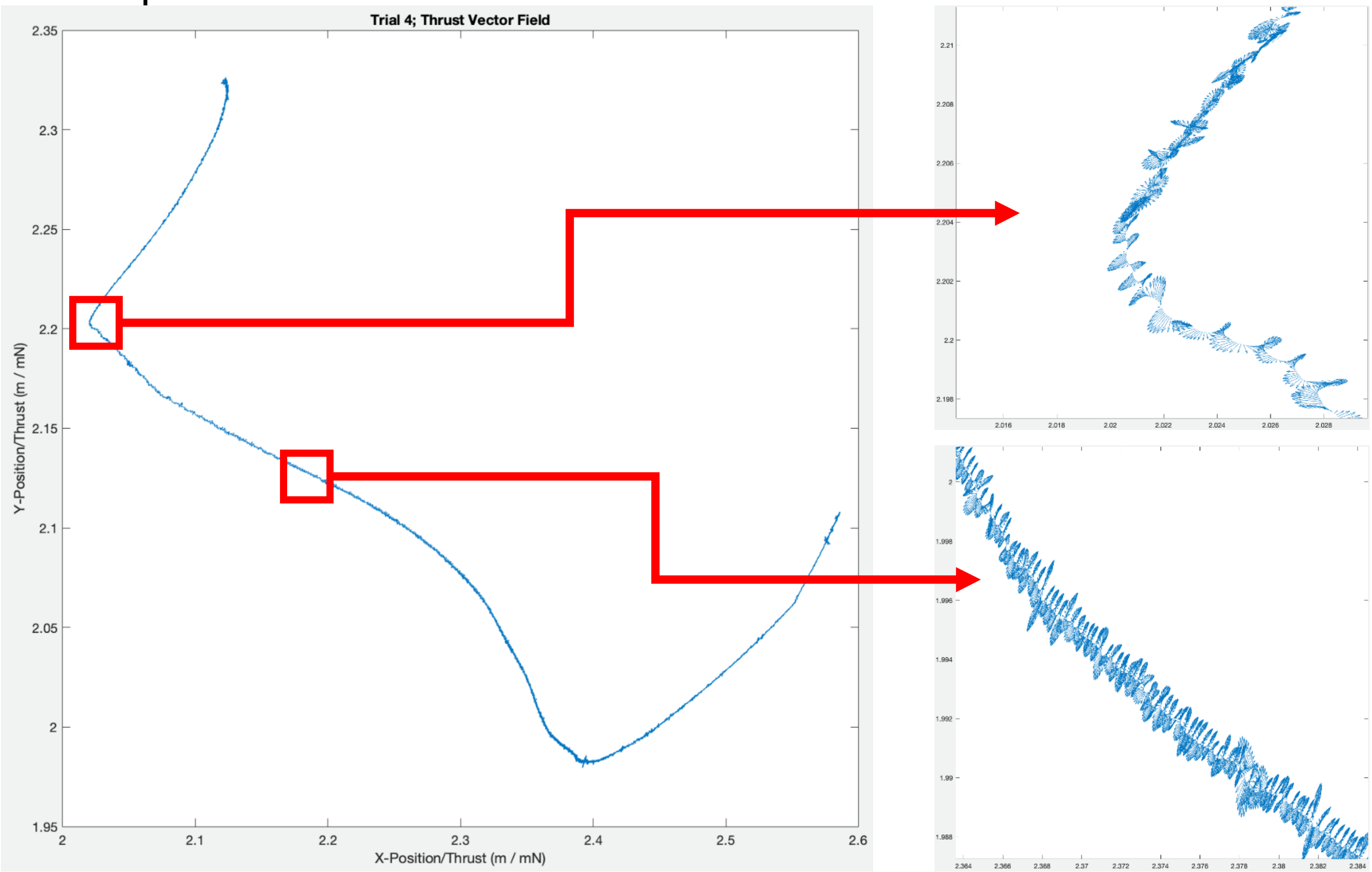
Average magnitude of Force	4.229 mN
Test Duration	7:19
Target Speed	245 RPM
Speed Range	245-238 RPM

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

Position Summary Data

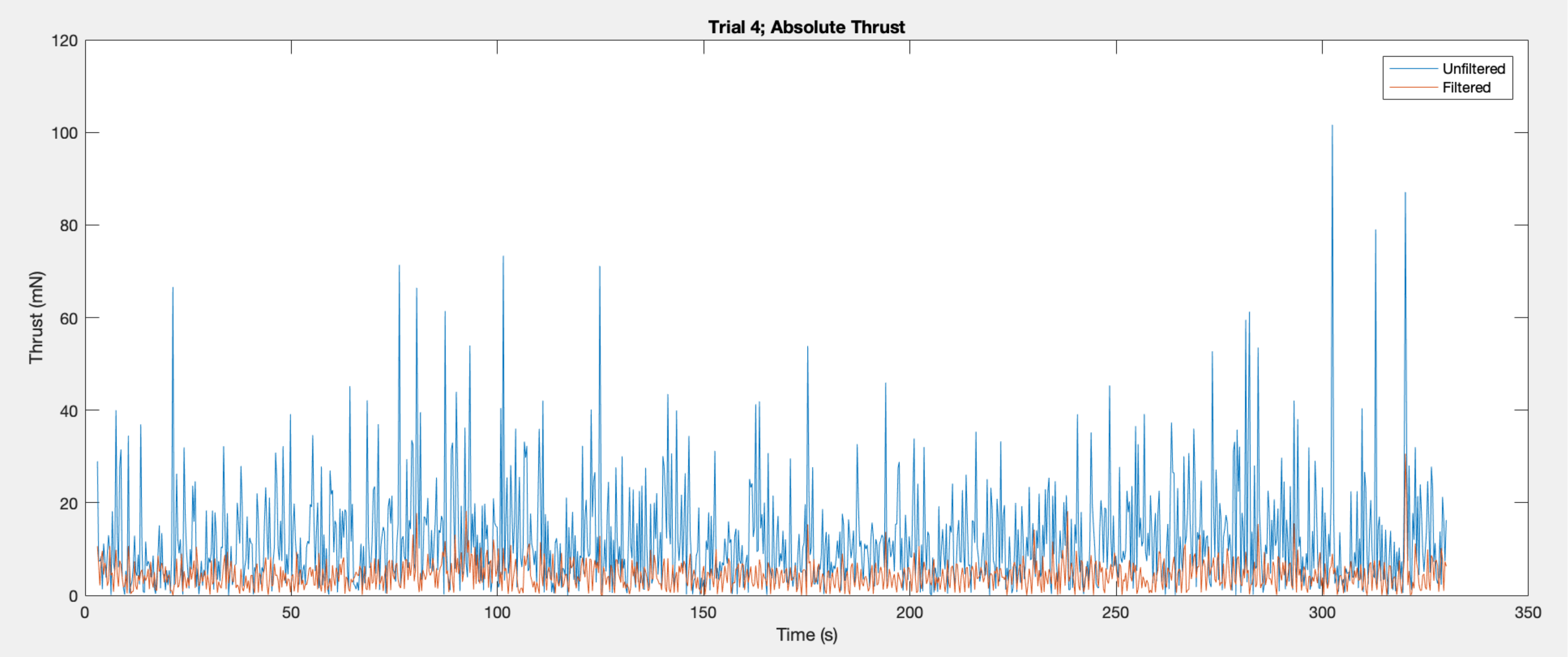
- **Trial 4 5/31/2019 11:53**

XY position as a function of time



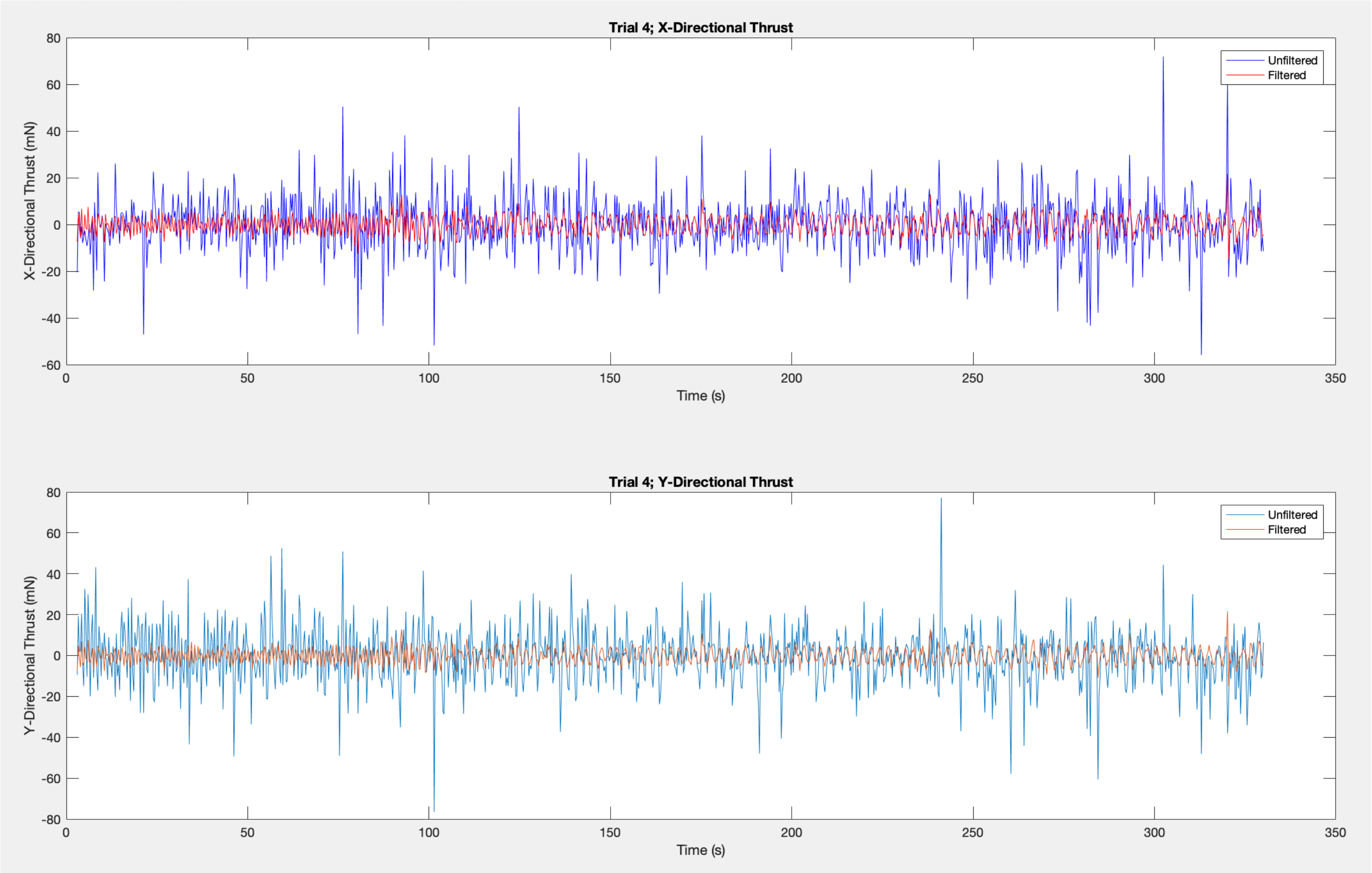
- **Trial 4   5/31/2019   11:53**

1. Force value obtained: Numerical Differentiation
2. Plot Filtering: Moving Mean & Savitsky-Golay Filtering
3. **Average Magnitude of Force = 4.229 mN**



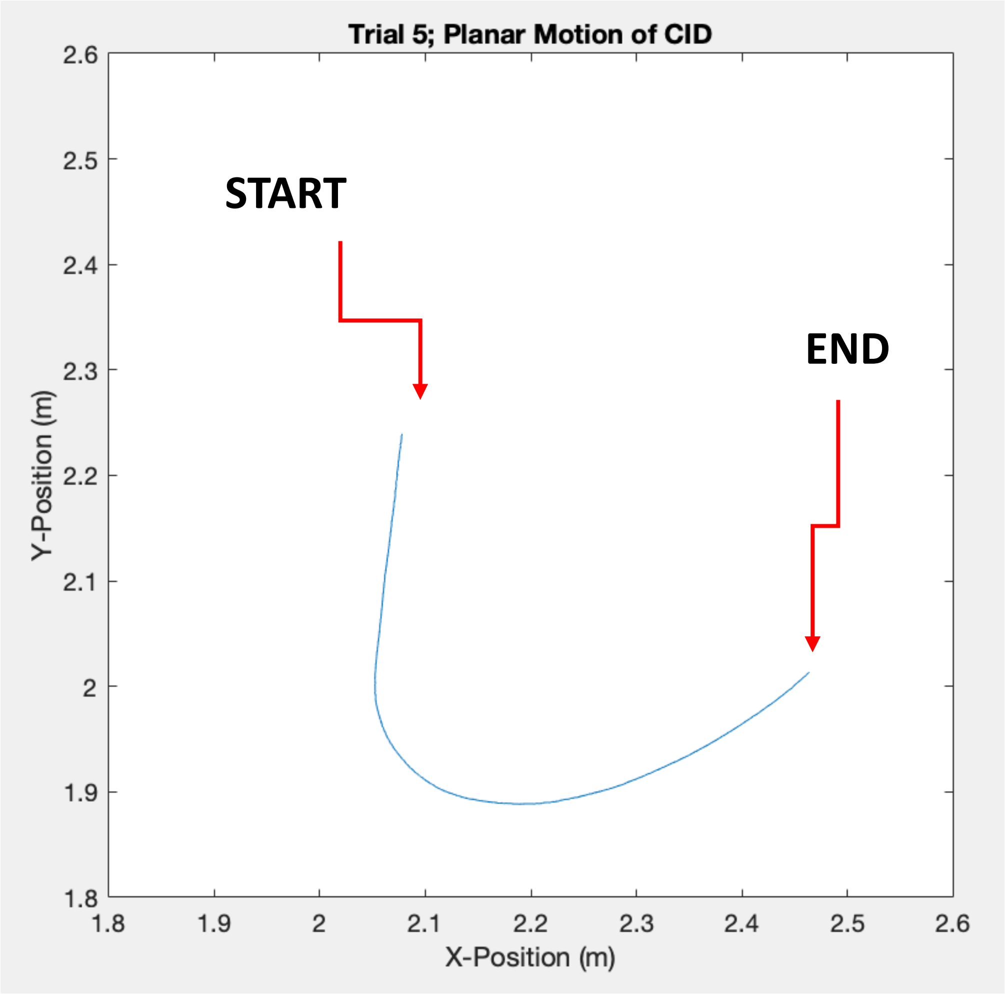
- **Trial 4 5/31/2019 11:53**

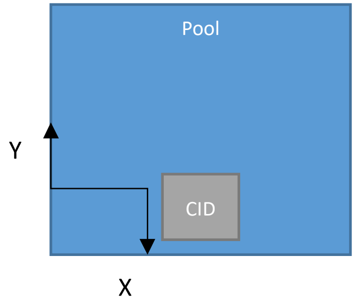
1. Force in the X and Y directions.



Position Summary Data

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



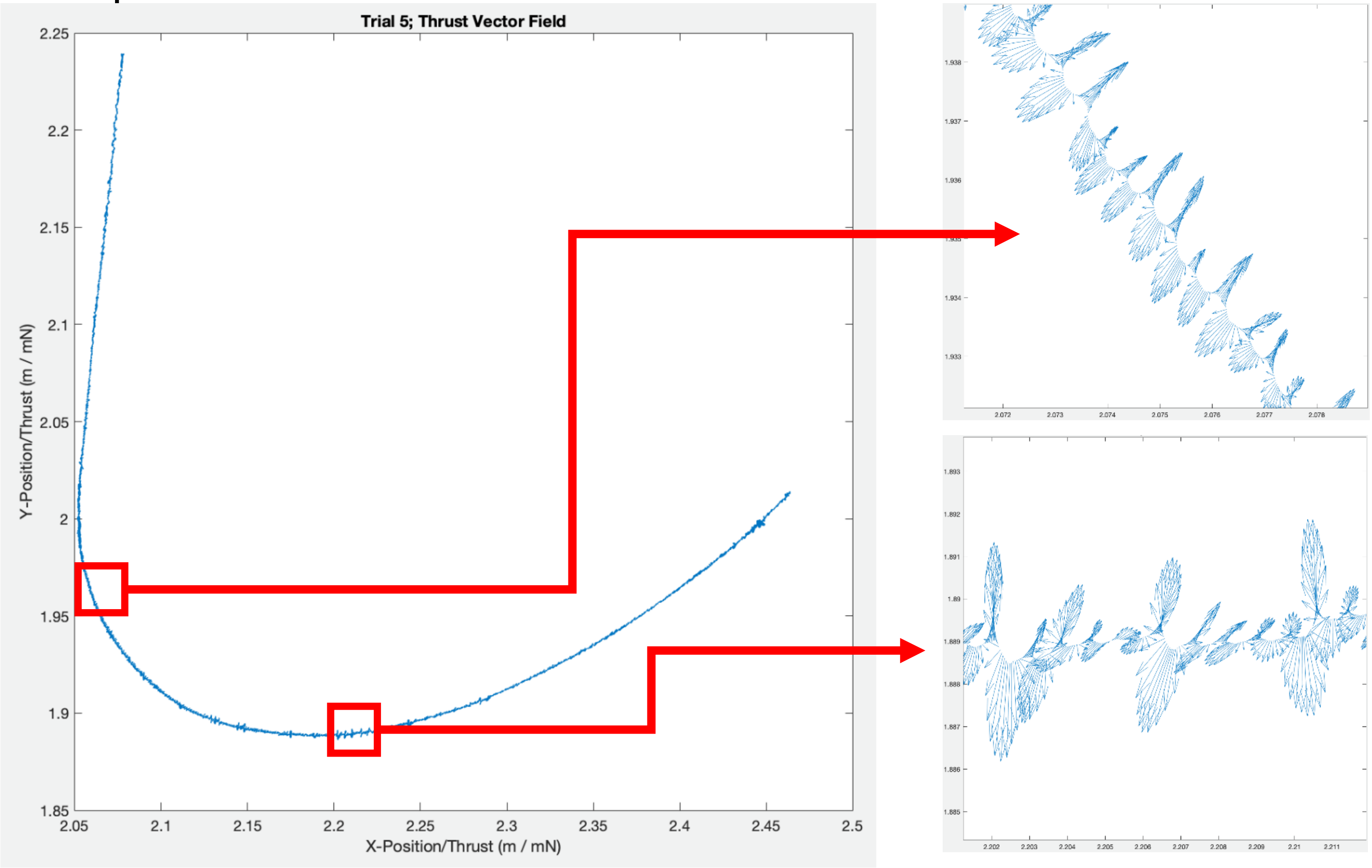


Average magnitude of Force	4.027 mN
Test Duration	3:23
Target Speed	240 RPM
Speed Range	240-233 RPM

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.

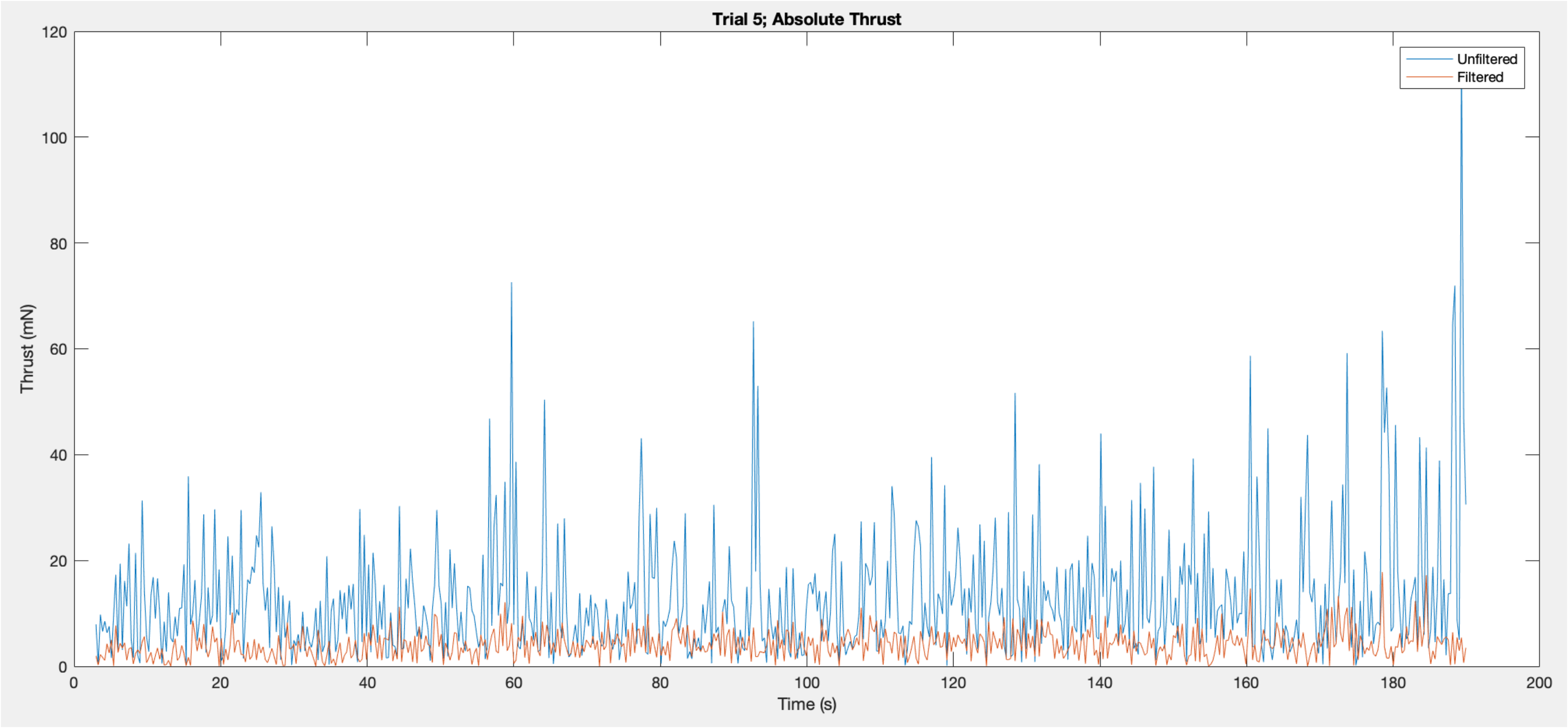
- **Trial 5 5/31/2019 12:22**

XY position as a function of time



Force Summary

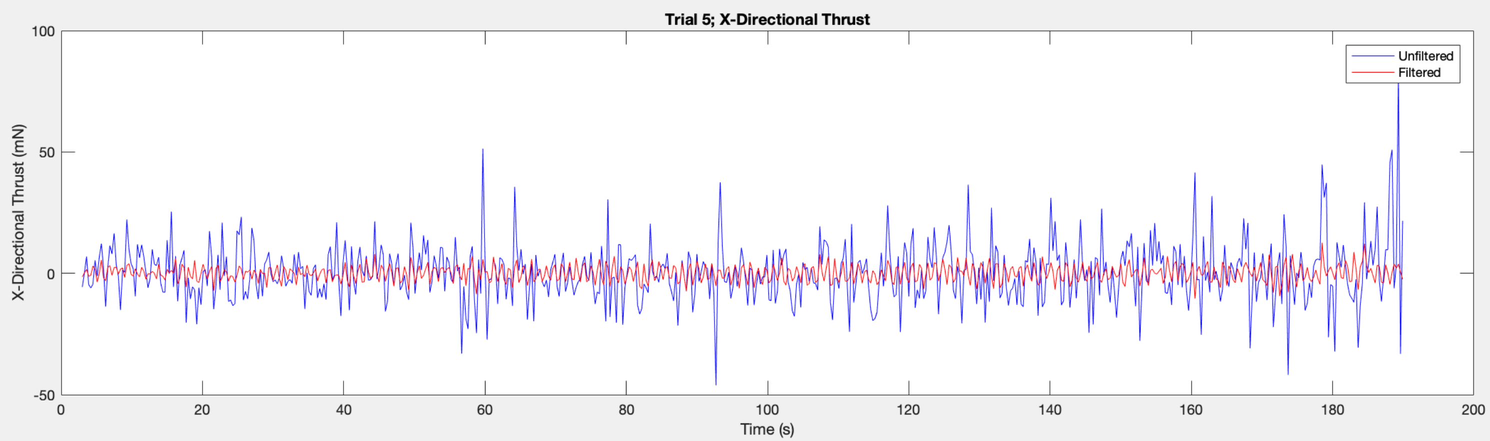
- **Trial 5   5/31/2019   12:22**
  1. Force value obtained: Numerical Differentiation
  2. Plot Filtering: Moving Mean & Savitsky-Golay Filtering
  3. **Average Magnitude of Force = 4.027 mN**

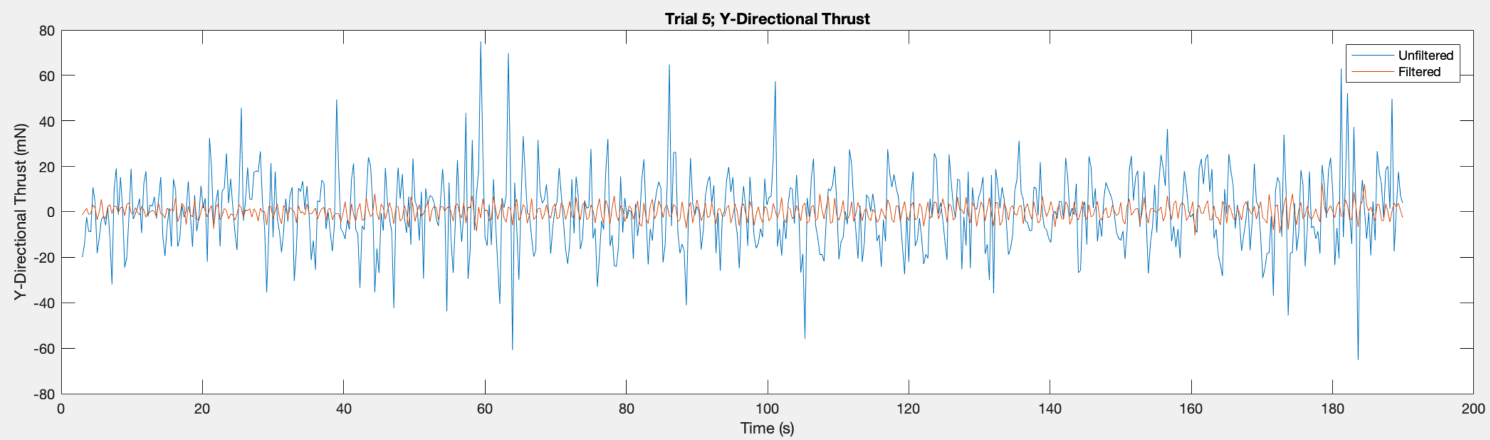


Force Summary

- **Trial 5   5/31/2019   12:22**

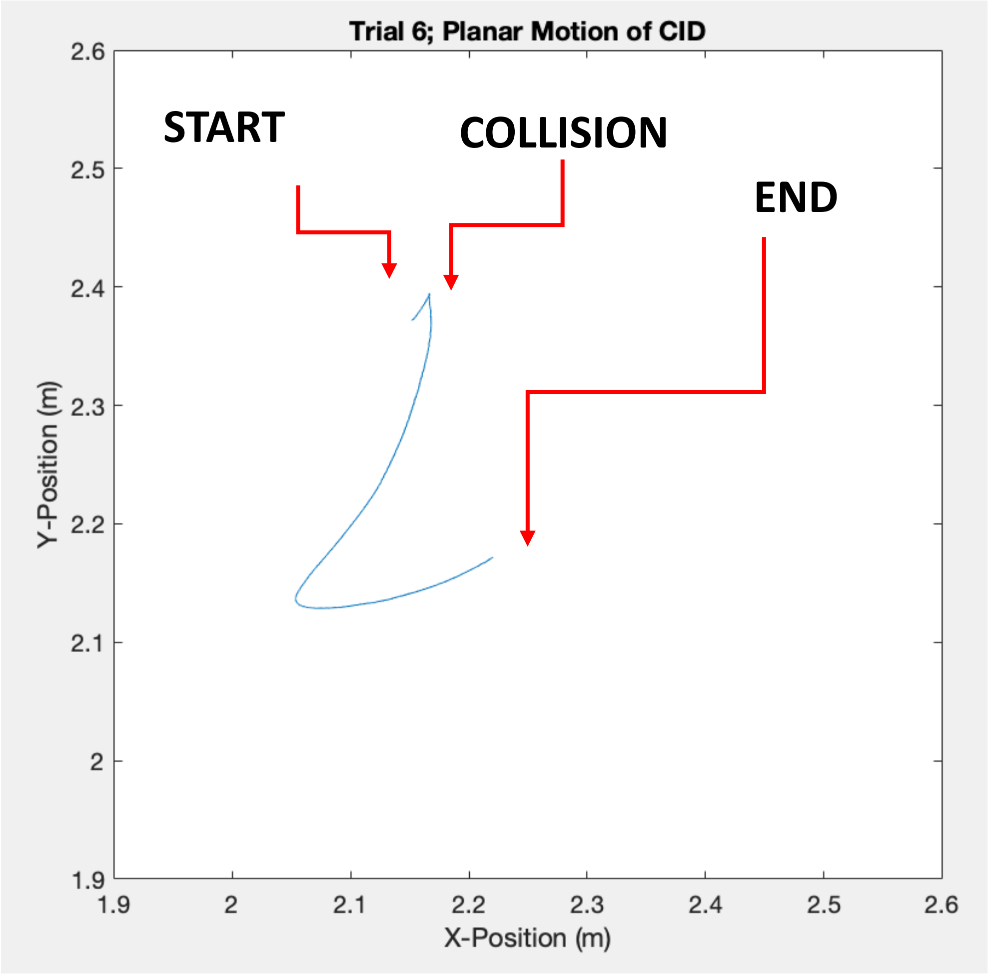
1. Force in the X and Y directions.

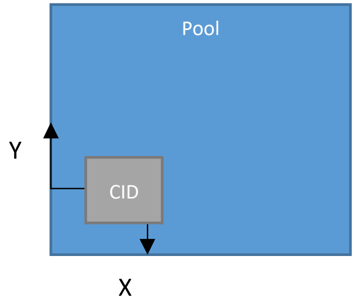




Position Summary Data

- **Trial 6** demonstrated net translational + rotational motion.



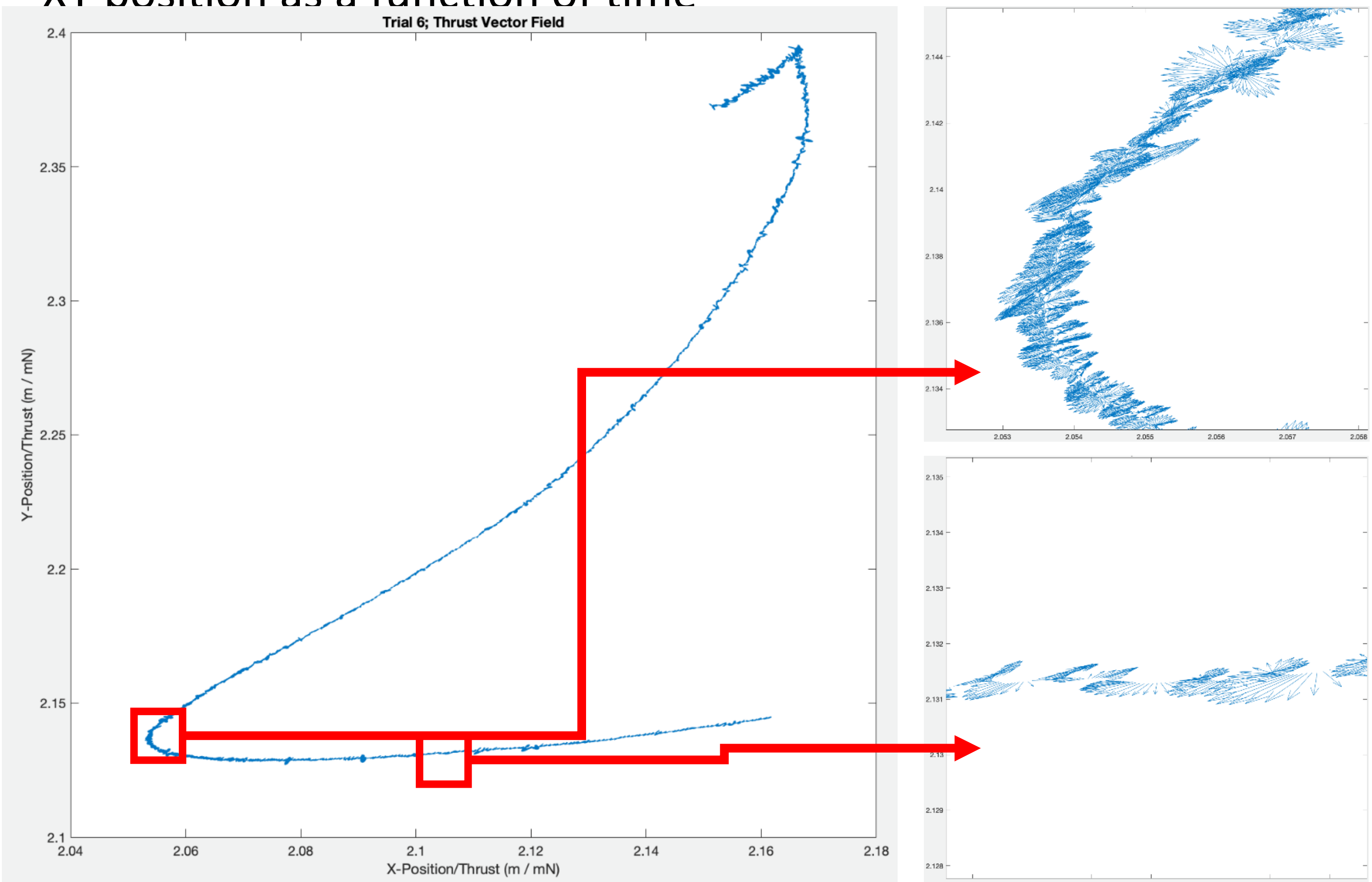


Average Thrust	3.412 mN
Average magnitude of Force	4:05
Target Speed	240 RPM
Speed Range	240-234 RPM

Edge of CID rotated in a way that caused it to minority graze the side of the pool within the first 30 seconds of testing.

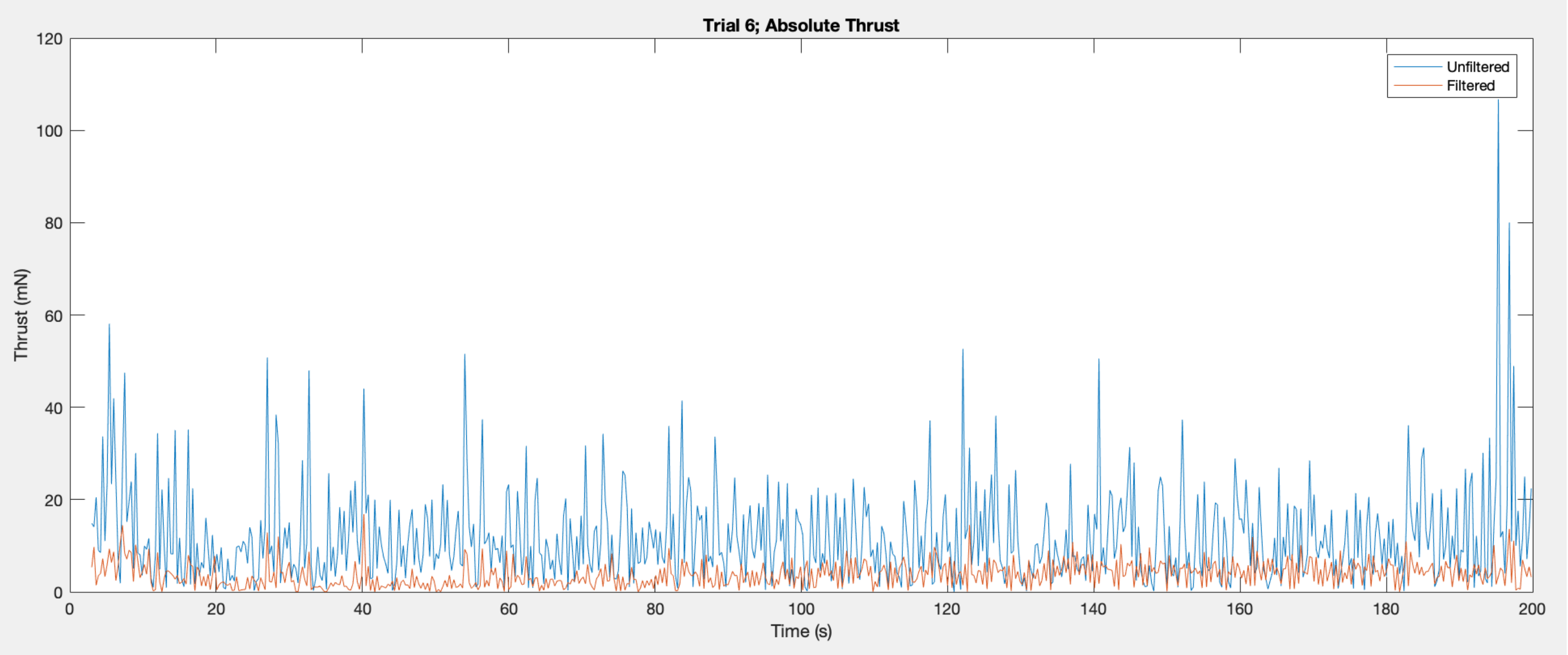
- **Trial 6   5/31/2019   12:34**

XY position as a function of time



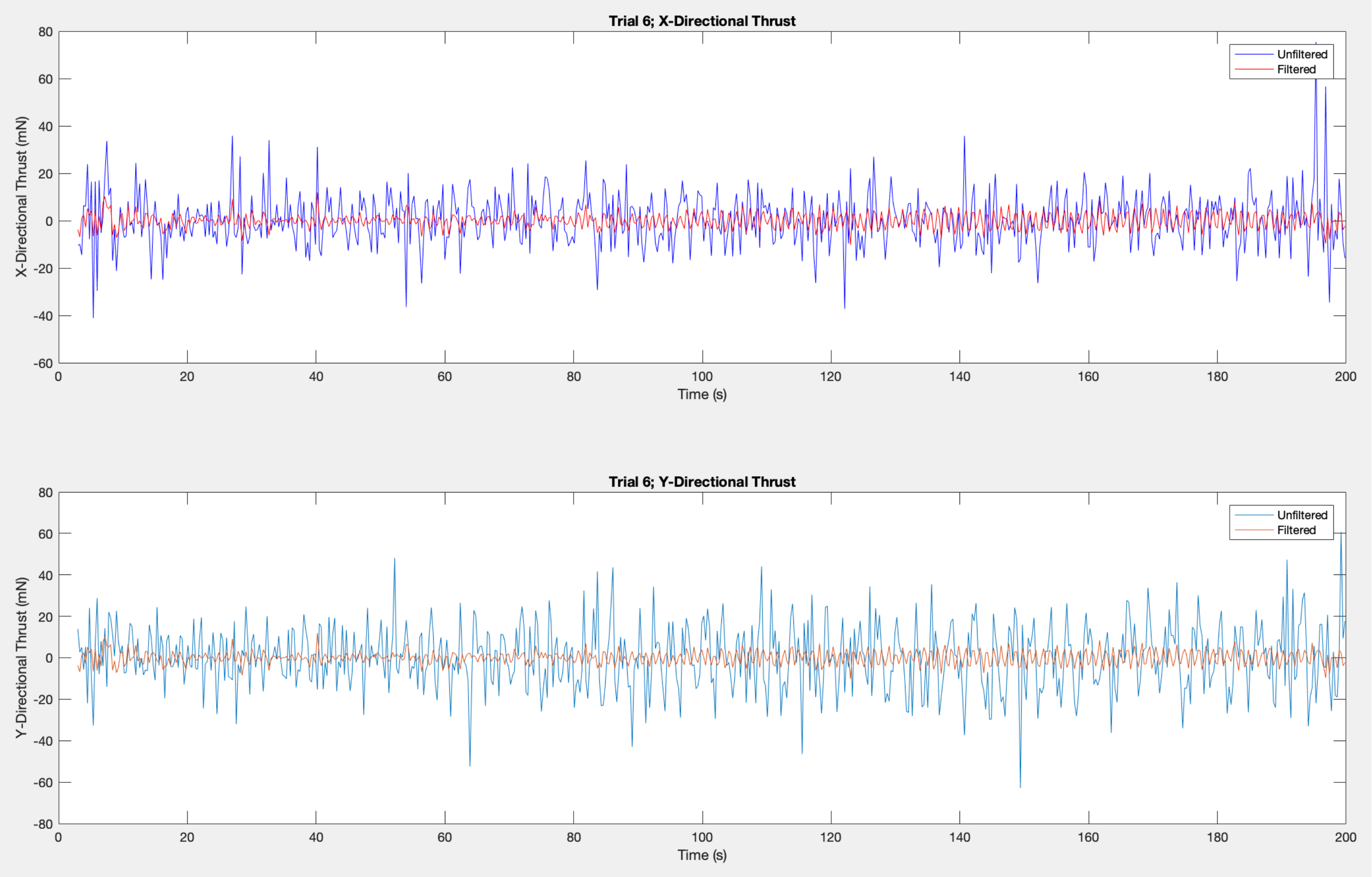
Force Summary

- **Trial 6 5/31/2019 12:34**
  1. Force value obtained: Numerical Differentiation
  2. Plot Filtering: Moving Mean & Savitsky-Golay Filtering
  3. **Average Magnitude of Force = 3.412 mN**



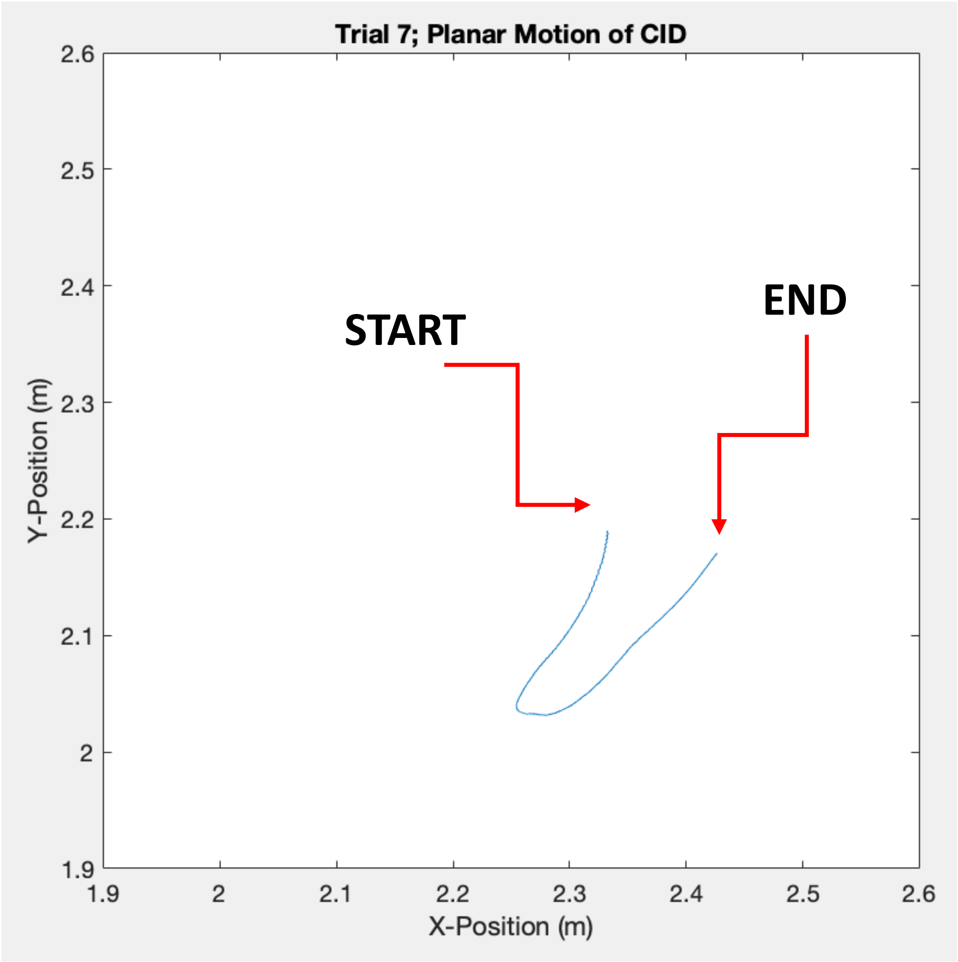
- **Trial 6 5/31/2019 12:34**

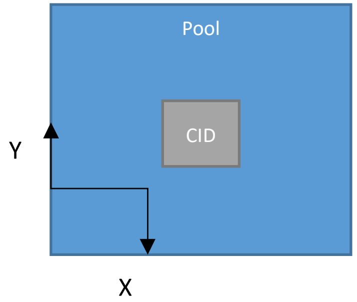
1. Force in the X and Y directions.



Position Summary Data

- **Trial 7** demonstrated net translational + rotational motion.





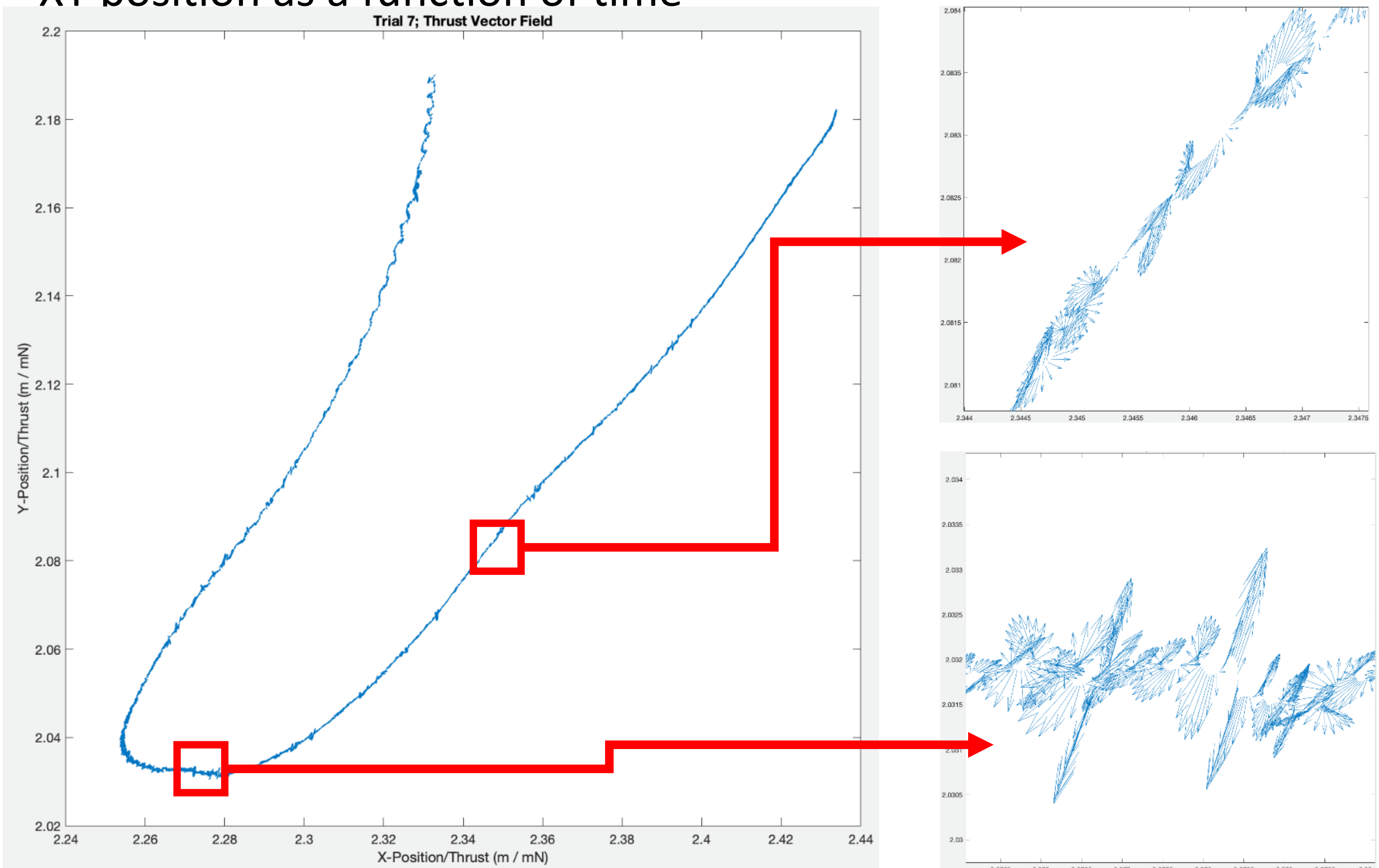
Average magnitude of Force	4.498 mN
Test Duration	2:33
Target Speed	240 RPM
Speed Range	240-238 RPM

Our sponsor noted that the rotating CID pistons produced the correct "shape" when rotating between 240-248 RPM.

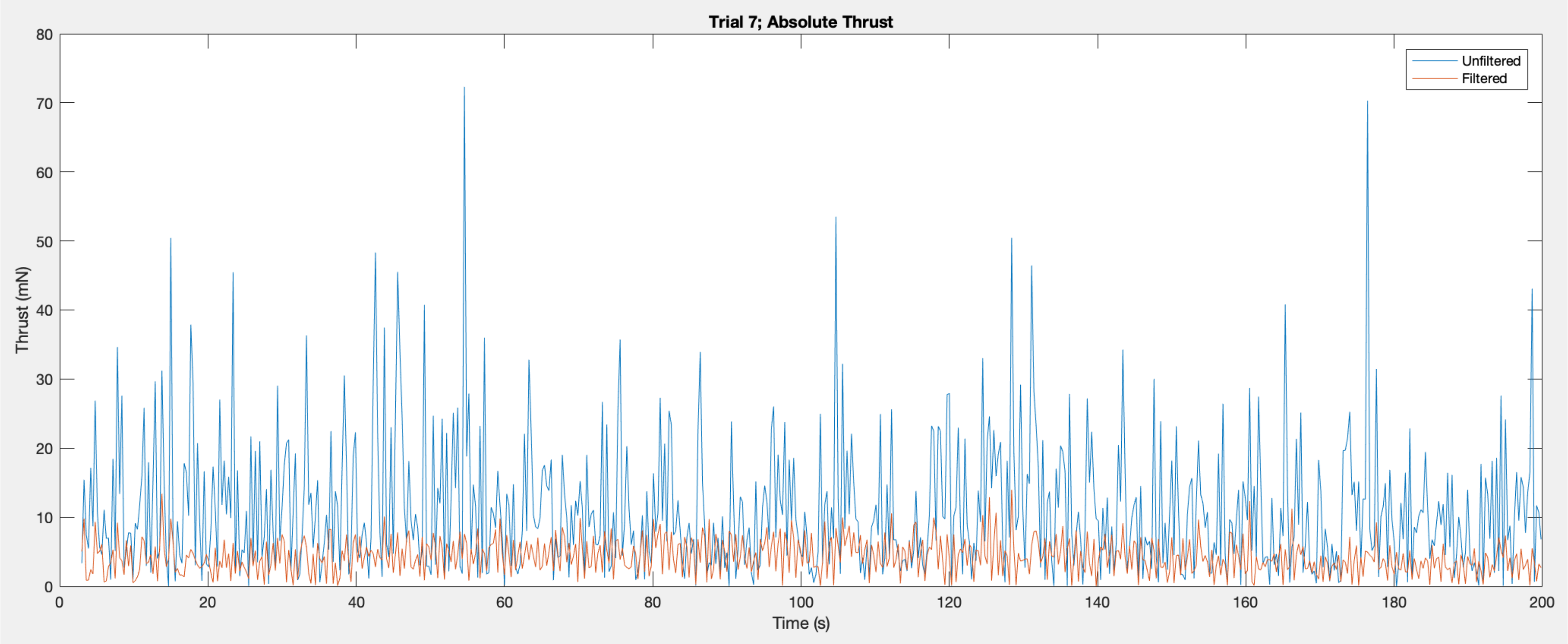
Position Summary Data

- **Trial 7   5/31/2019   14:34**

XY position as a function of time

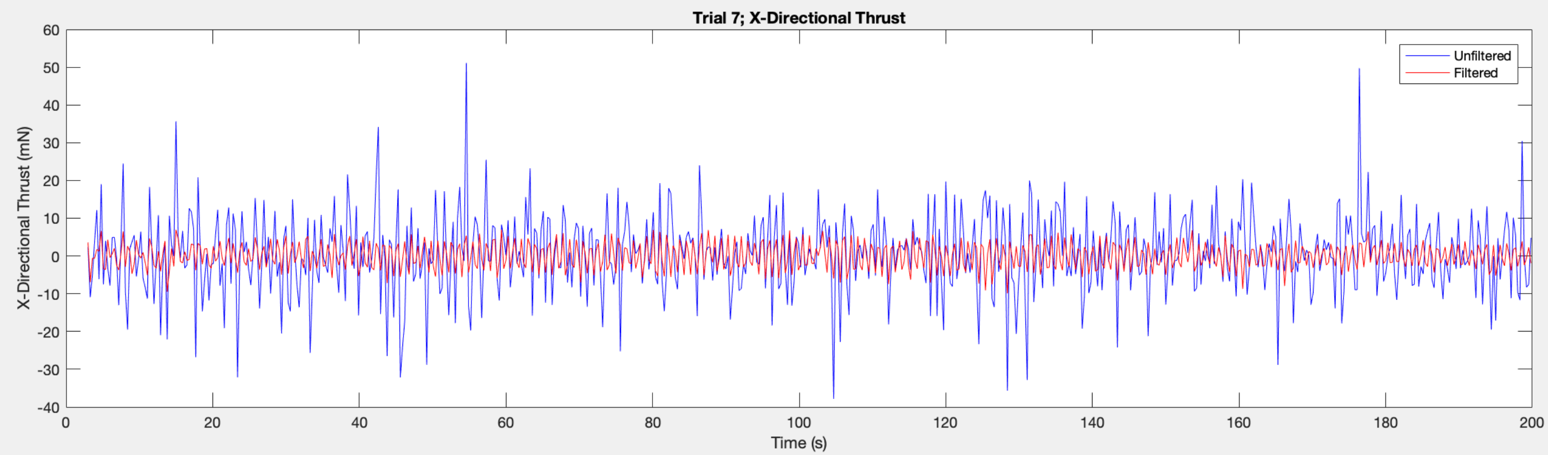


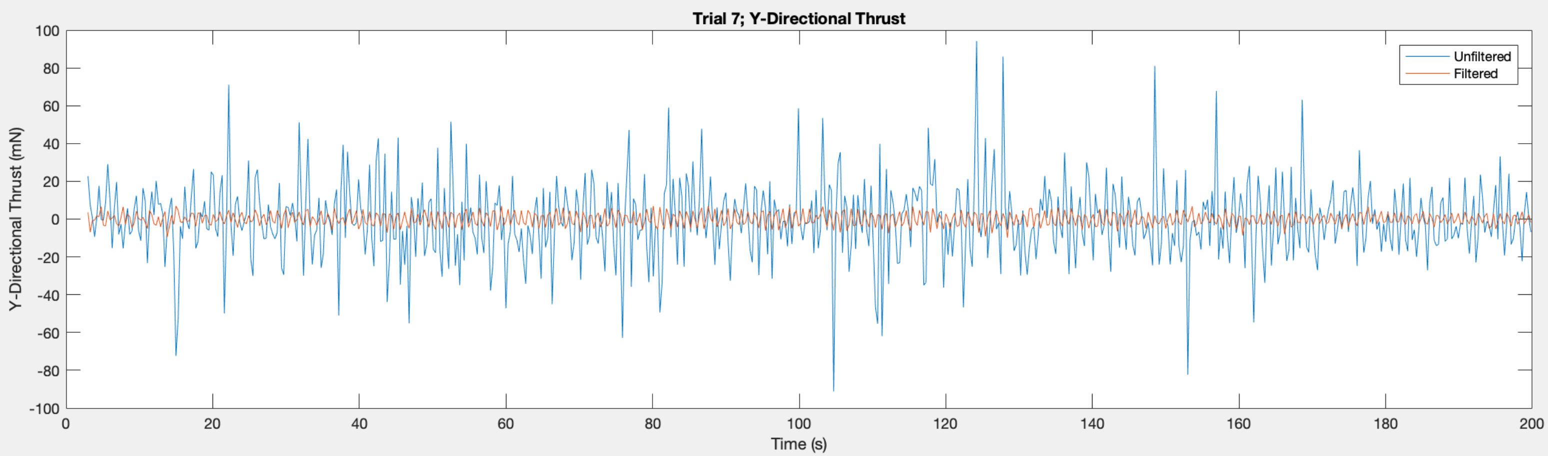
- **Trial 7 5/31/2019 14:34**
  1. Force value obtained: Numerical Differentiation.
  2. Plot Filtering: Moving Mean & Savitsky-Golay Filtering.
  3. **Average Magnitude of Force = 4.498 mN.**



- **Trial 7   5/31/2019   14:34**

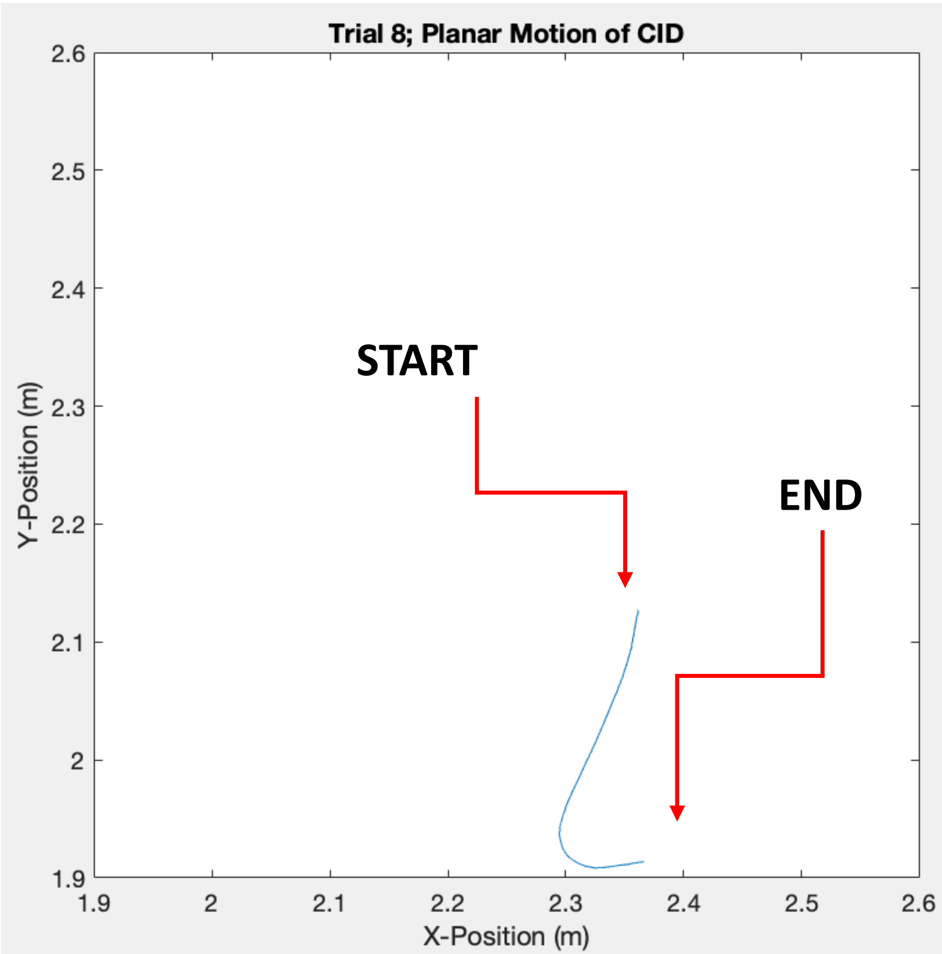
1. Force in the X and Y directions.

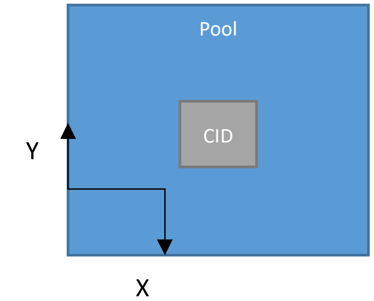




Position Summary Data

- **Trial 8** demonstrated net translational + rotational motion.





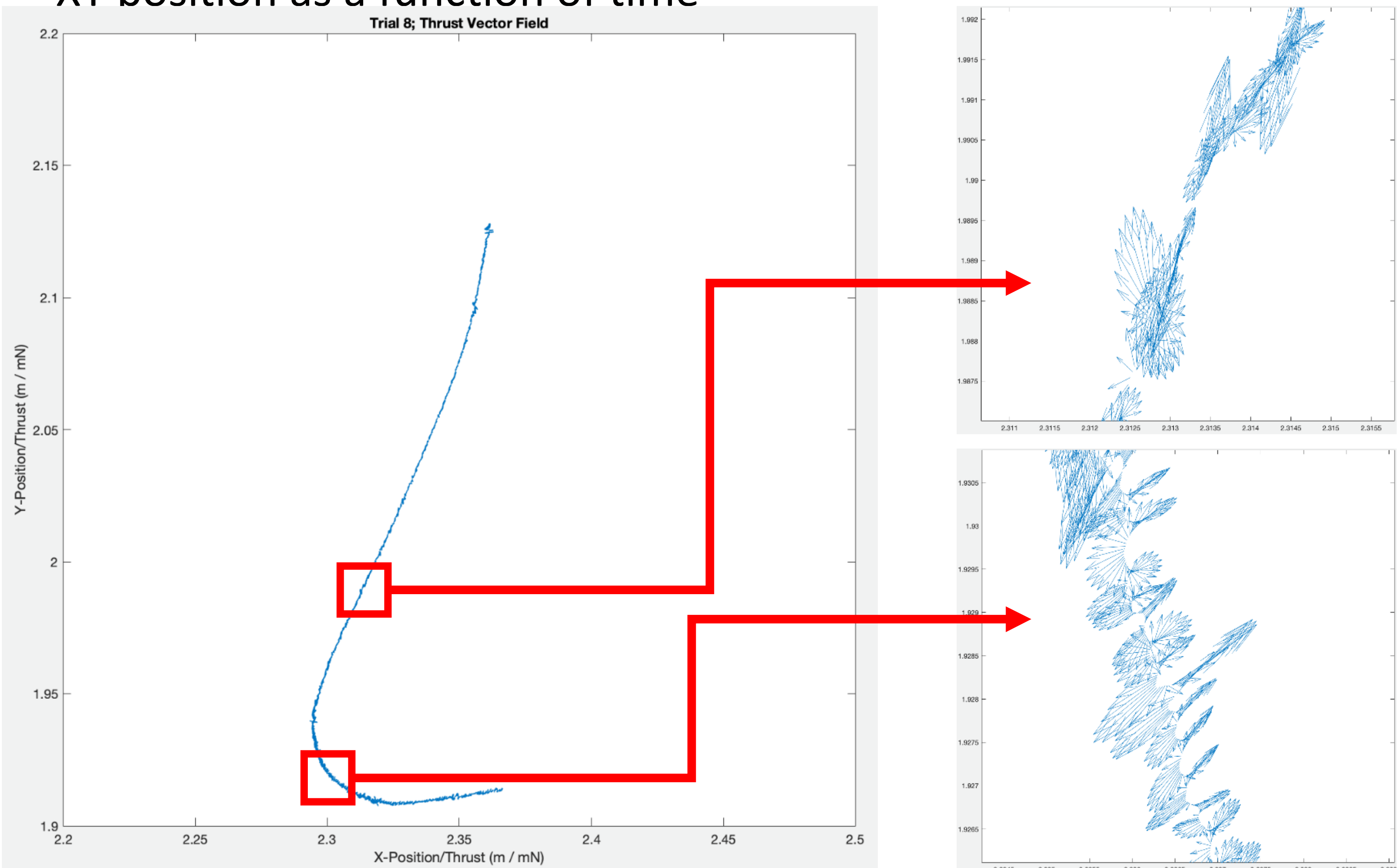
Average magnitude of Force	3.853 mN
Test Duration	3:23
Target Speed	237 RPM
Speed Range	237-235 RPM

Our sponsor noted that, from a visual standpoint, the ideal “shape” can no longer be seen in the range of 236 RPM to 235 RPM.

Position Summary Data

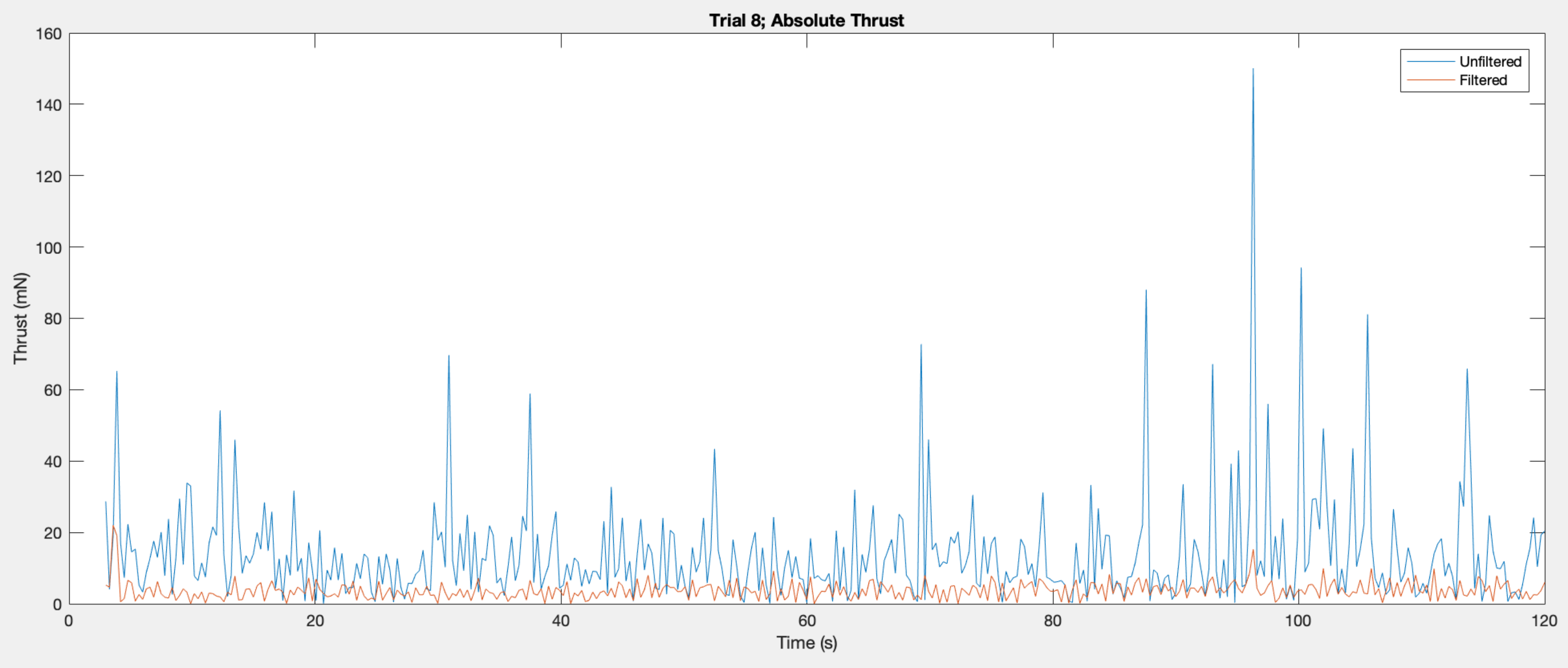
- **Trial 8   5/31/2019   14:44**

XY position as a function of time



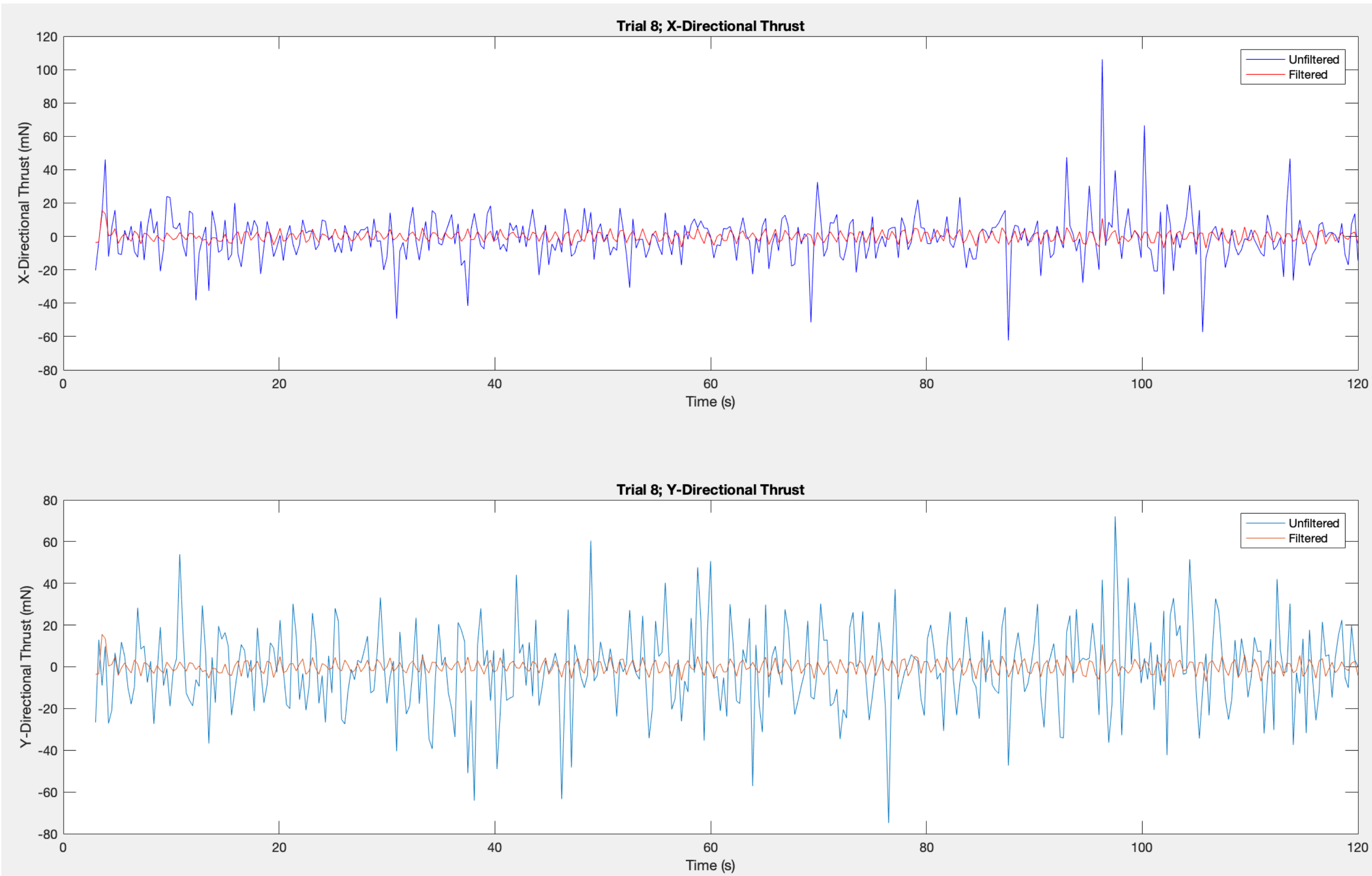
- **Trial 8 5/31/2019 14:44**

1. Thrust value obtained: Numerical Differentiation
2. Plot Filtering: Moving Mean & Savitsky-Golay Filtering
3. **Average Magnitude of Force = 3.853 mN**



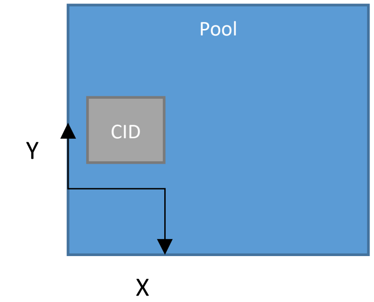
- **Trial 8   5/31/2019   14:44**

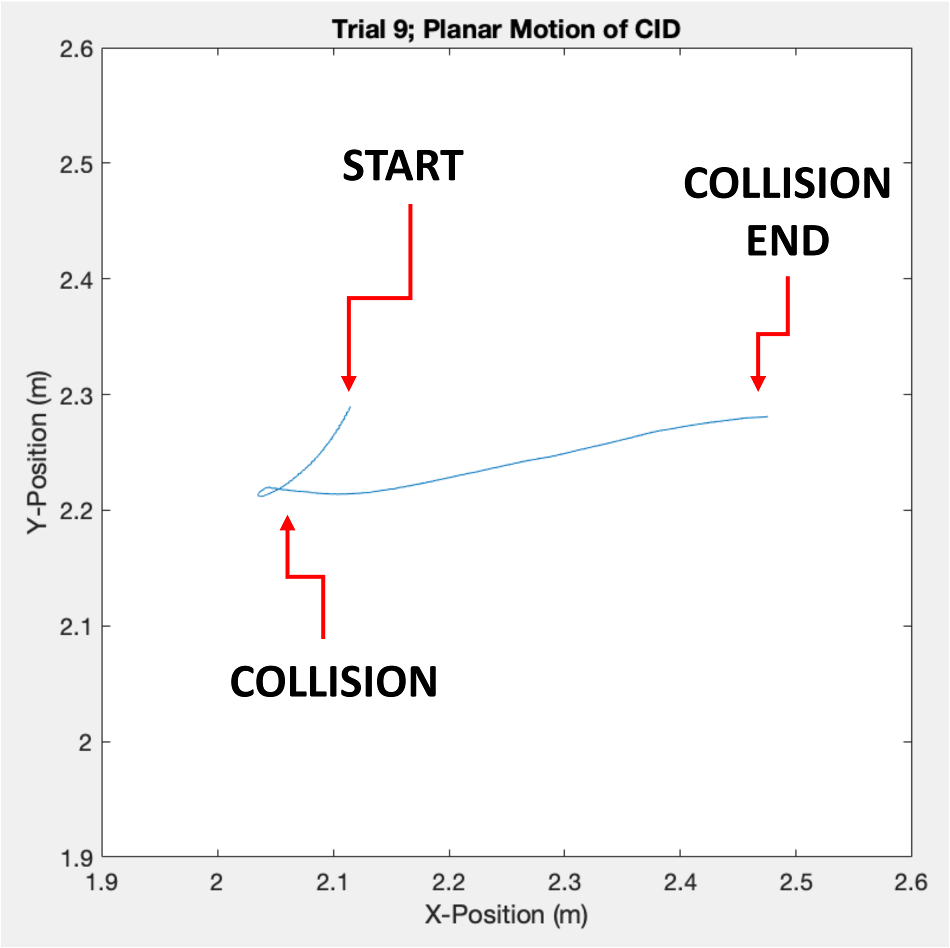
1. Force in the X and Y directions.



Position Summary Data

- **Trial 9** demonstrated net translational + rotational motion.





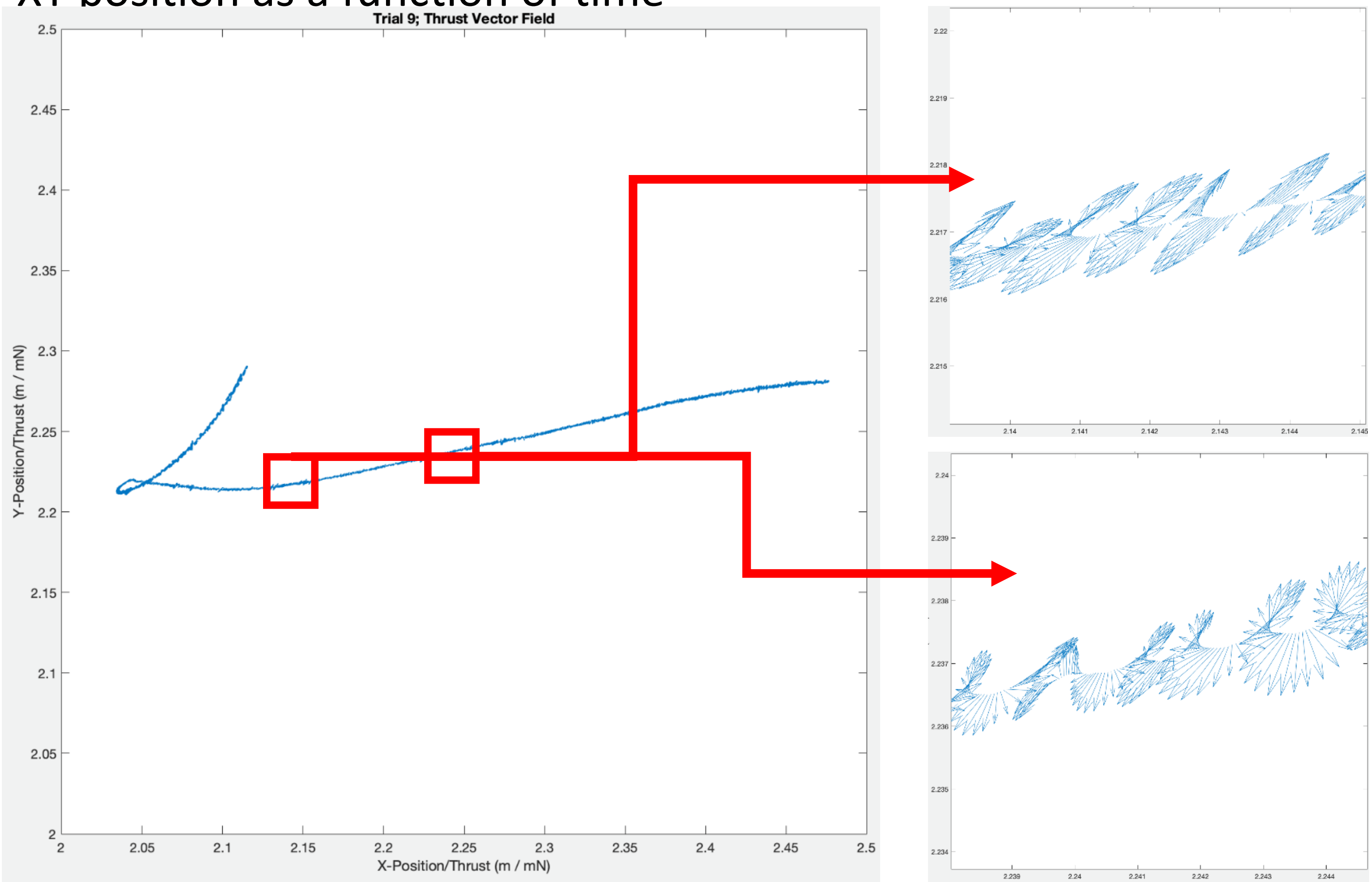
Average magnitude of Force	4.292 mN
Test Duration	4:33
Target Speed	242 RPM
Speed Range	242-236 RPM

The CID hit the edge of the pool approximately 2 minutes into the test. Hit the other wall at the opposite end of the pool during the end of out trail.

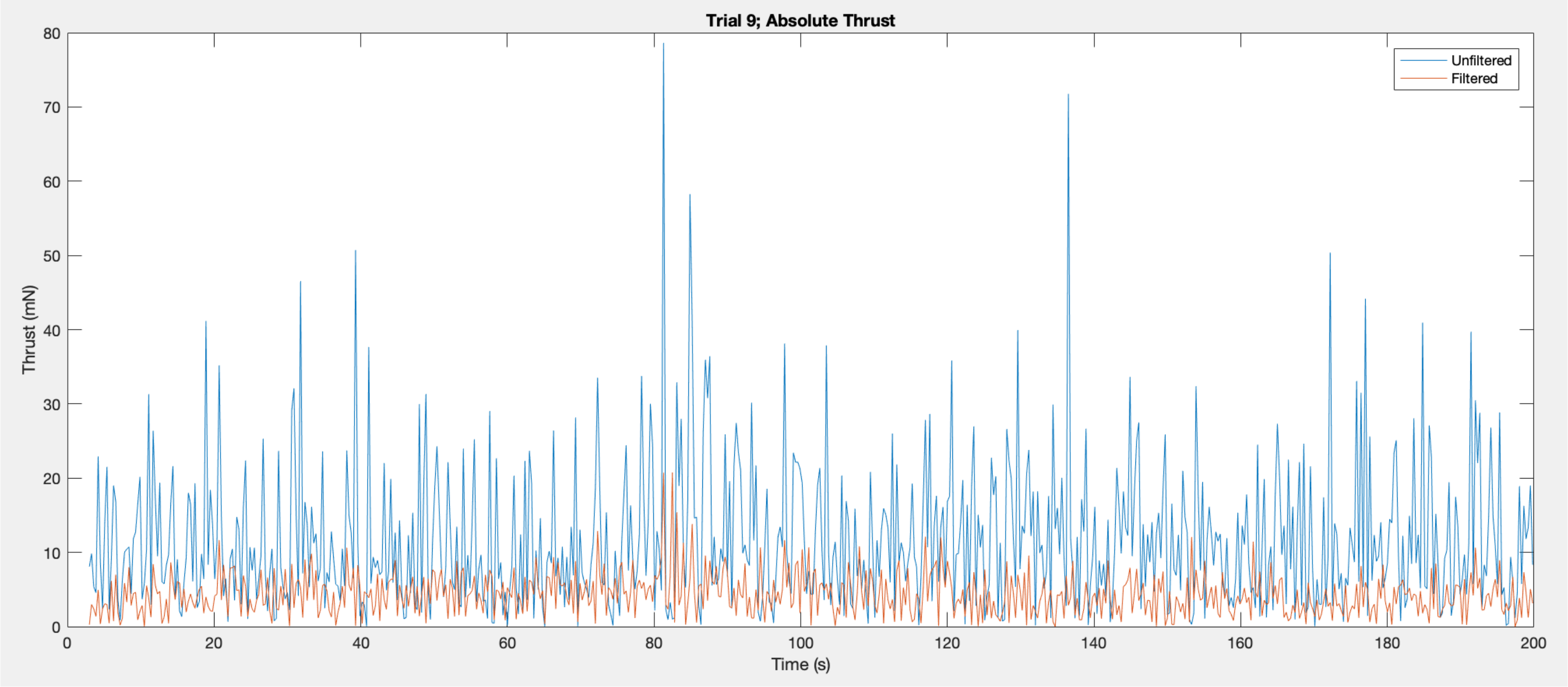
Position Summary Data

- **Trial 9 5/31/2019 14:55**

XY position as a function of time

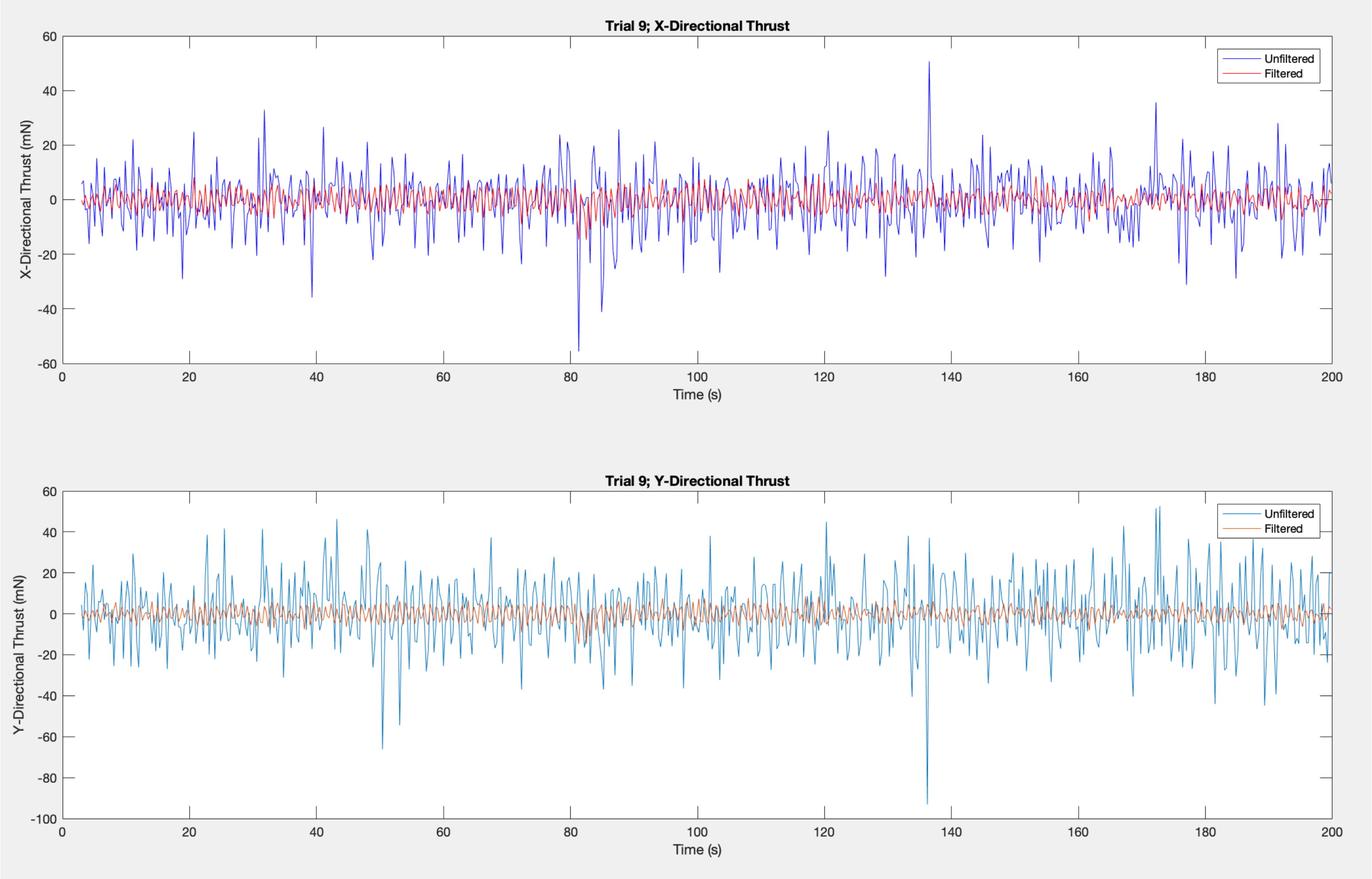


- **Trial 9 5/31/2019 14:55**
  1. Force value obtained: Numerical Differentiation
  2. Plot Filtering: Moving Mean & Savitsky-Golay Filtering
  3. **Average Magnitude of Force = 4.292 mN**



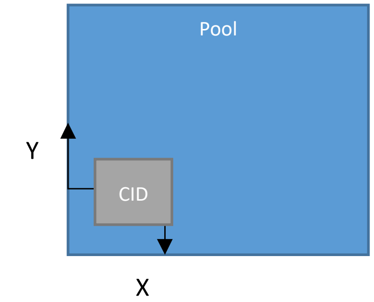
- **Trial 9 5/31/2019 14:55**

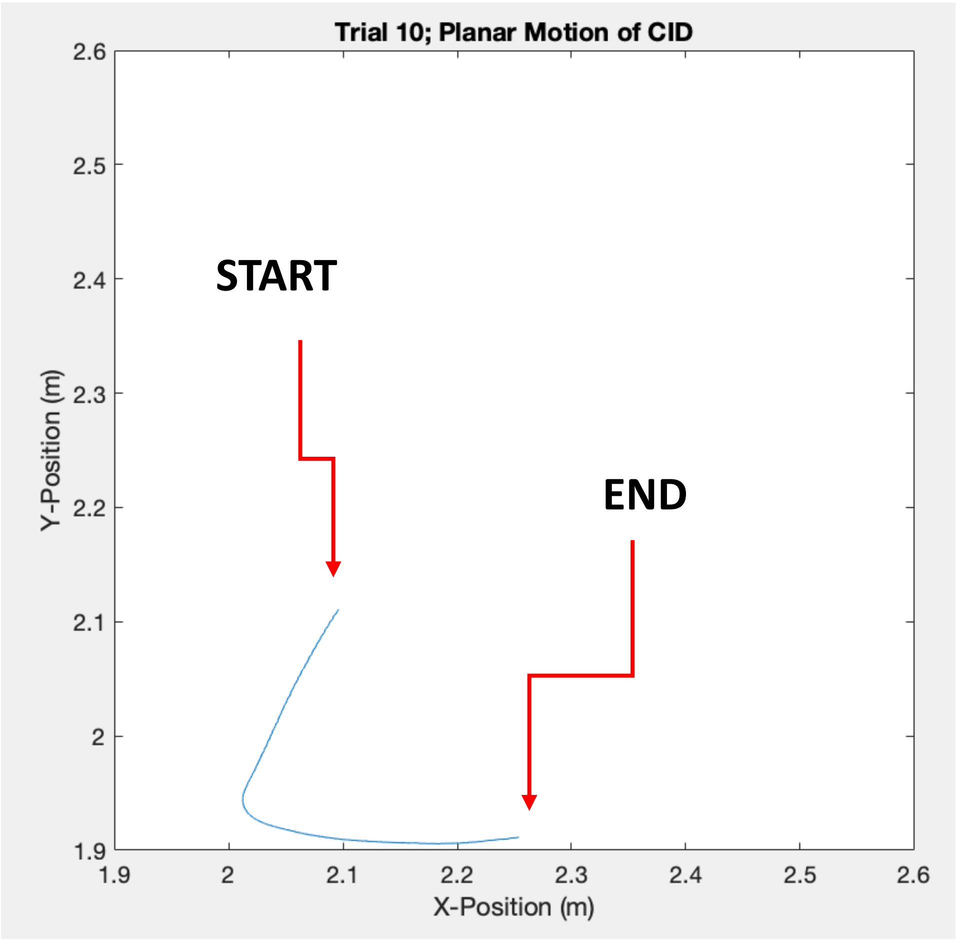
1. Force in the X and Y directions.



Position Summary Data

- **Trial 10** demonstrated net translational + rotational motion.



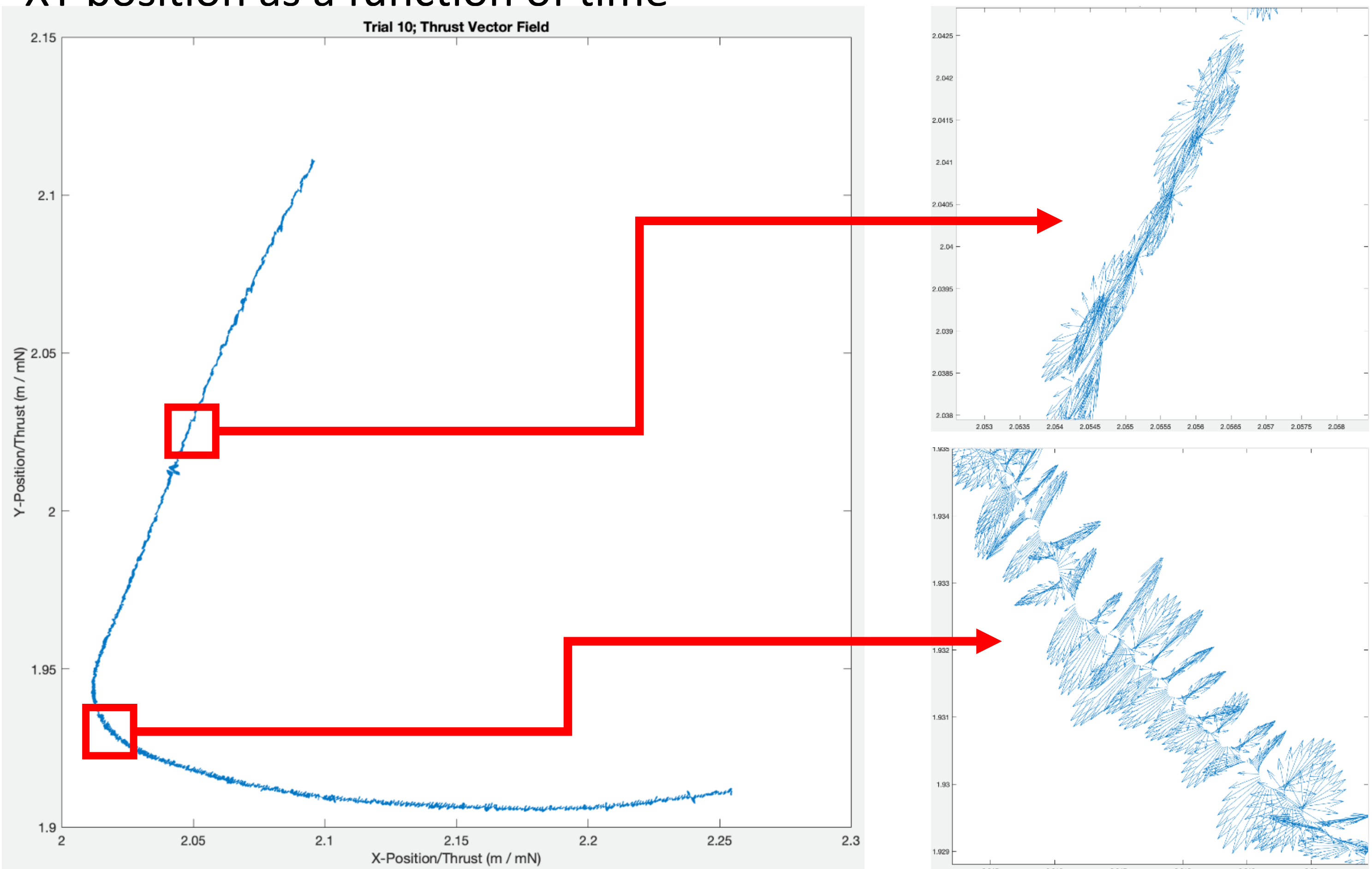


Average magnitude of Force	4.685 mN
Test Duration	2:45
Target Speed	242 RPM
Speed Range	242-237 RPM

Position Summary Data

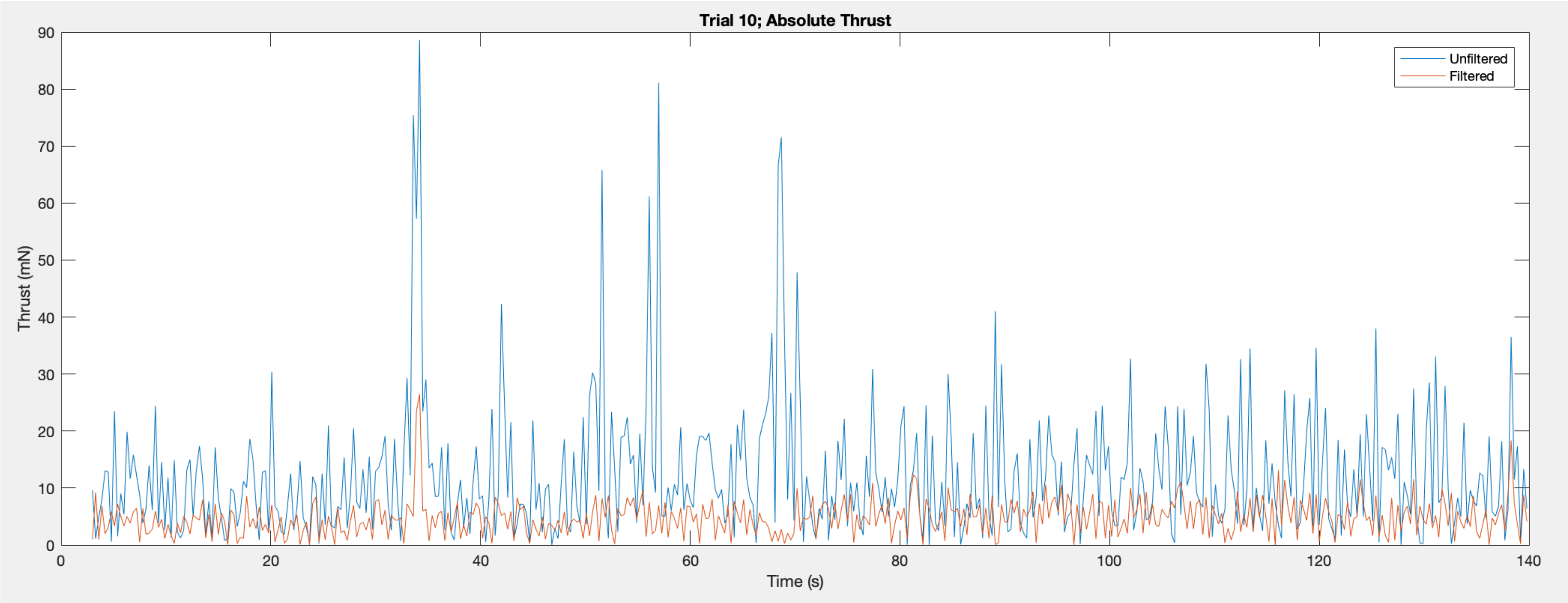
- **Trial 10 5/31/2019 15:07**

XY position as a function of time



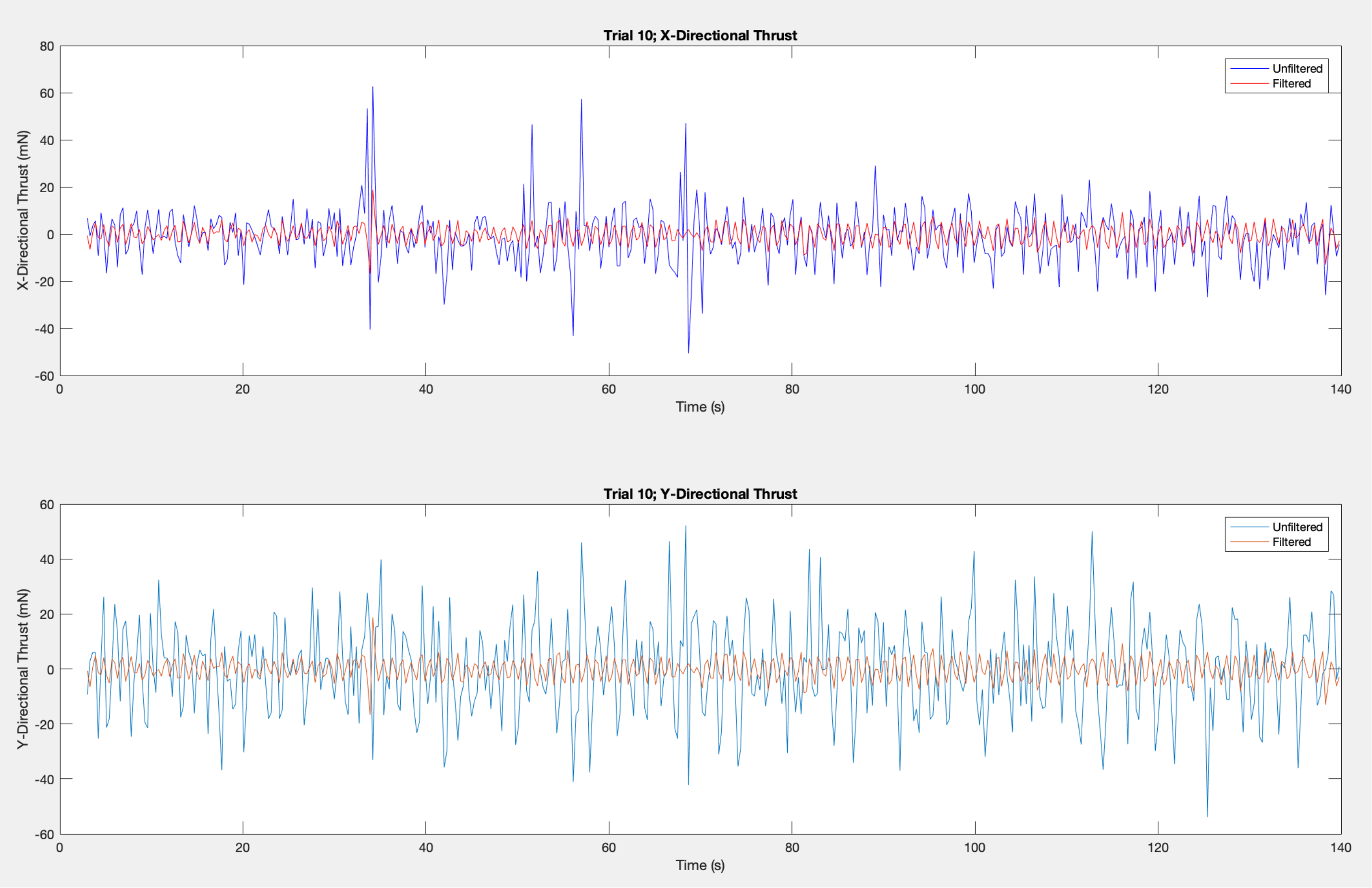
- **Trial 10   5/31/2019   15:07**

1. Force value obtained: Numerical Differentiation.
2. Plot Filtering: Moving Mean & Savitsky-Golay Filtering.
3. **Average Magnitude of Force = 4.685 mN.**



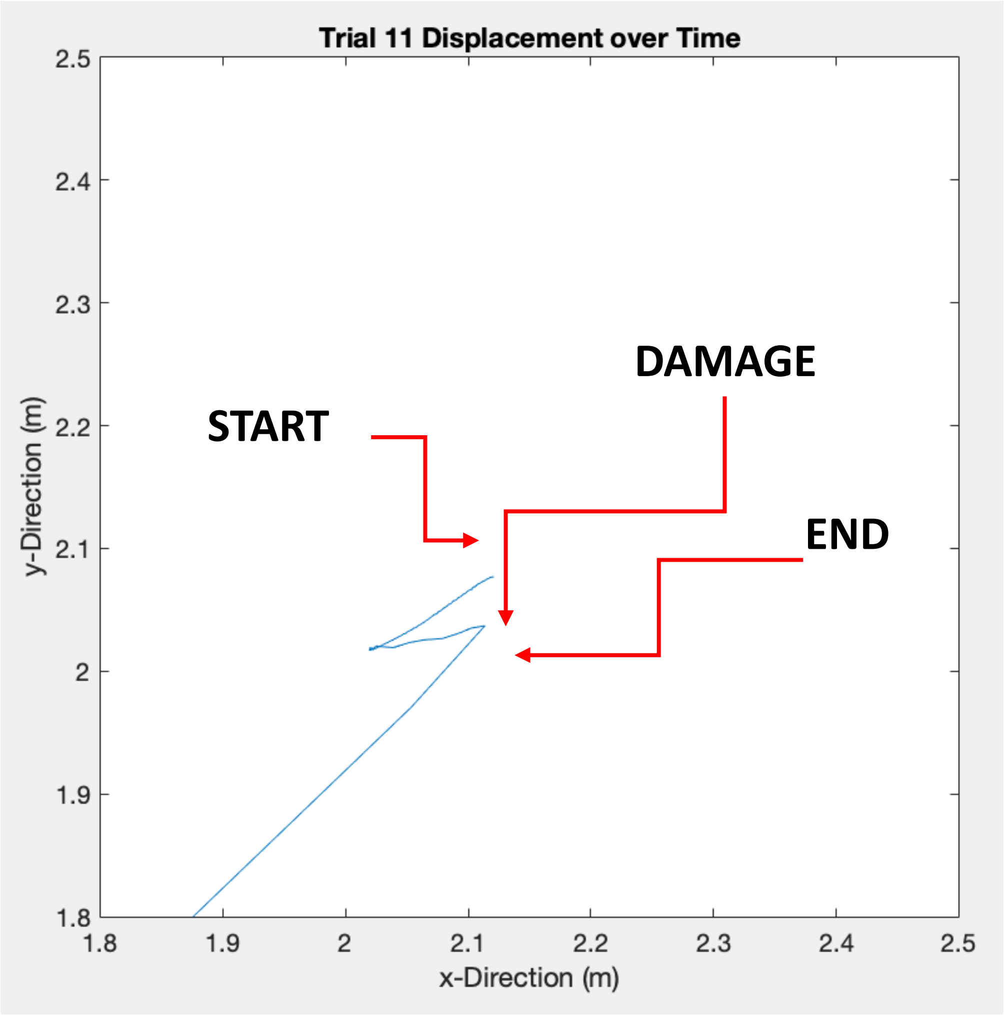
- **Trial 10   5/31/2019   15:07**

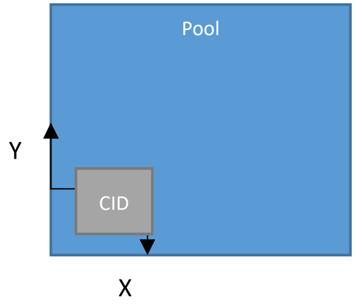
1. Force in the X and Y directions.



Position Summary Data

- **Trial 11** demonstrated net translational + rotational motion.



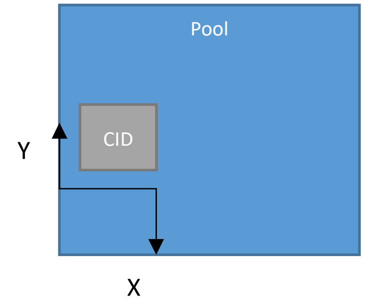


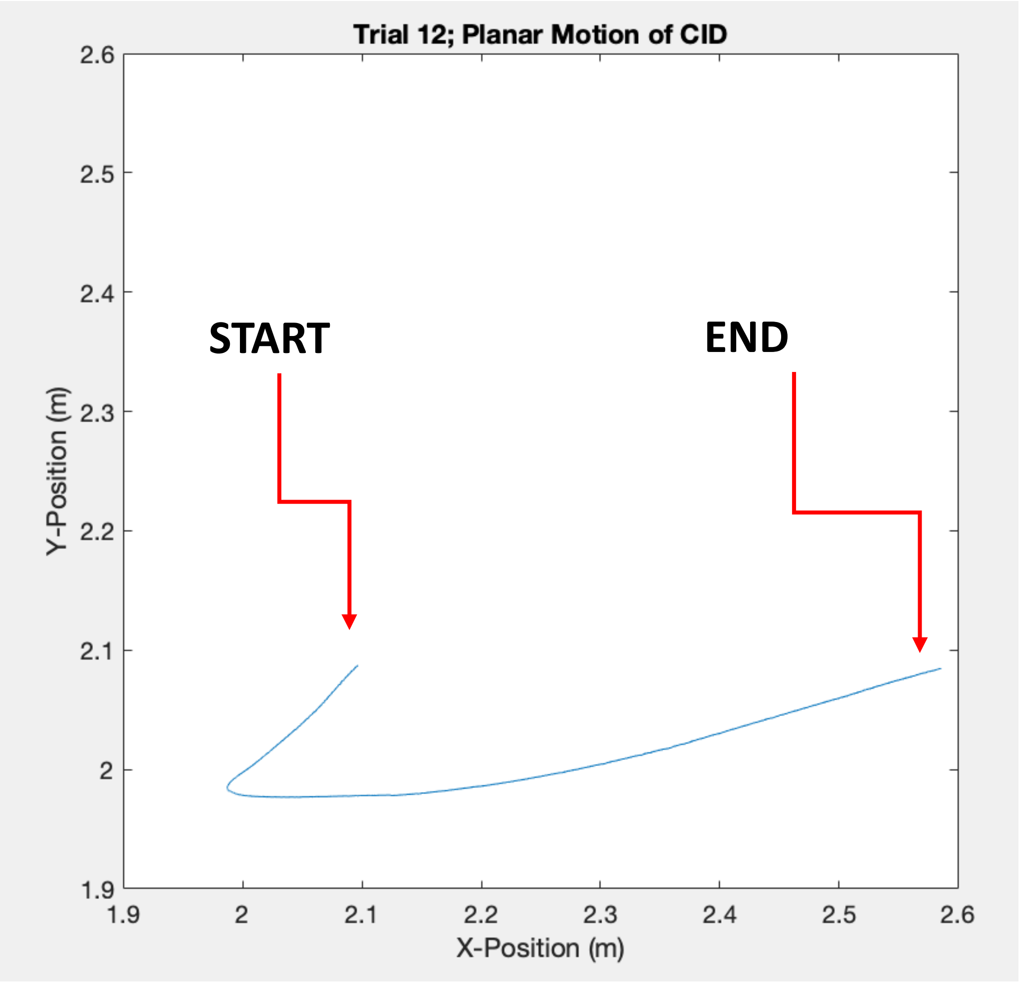
Average magnitude of Force	N/A
Test Duration	0:21
Target Speed	242 RPM
Speed Range	N/A

Repeated trial for a total of 3 times; one of the rotating magnet arm repeatedly came off from its piston; piston screw was replaced, but came back apart each time.

Position Summary Data

- **Trial 12** demonstrated net translational + rotational motion.



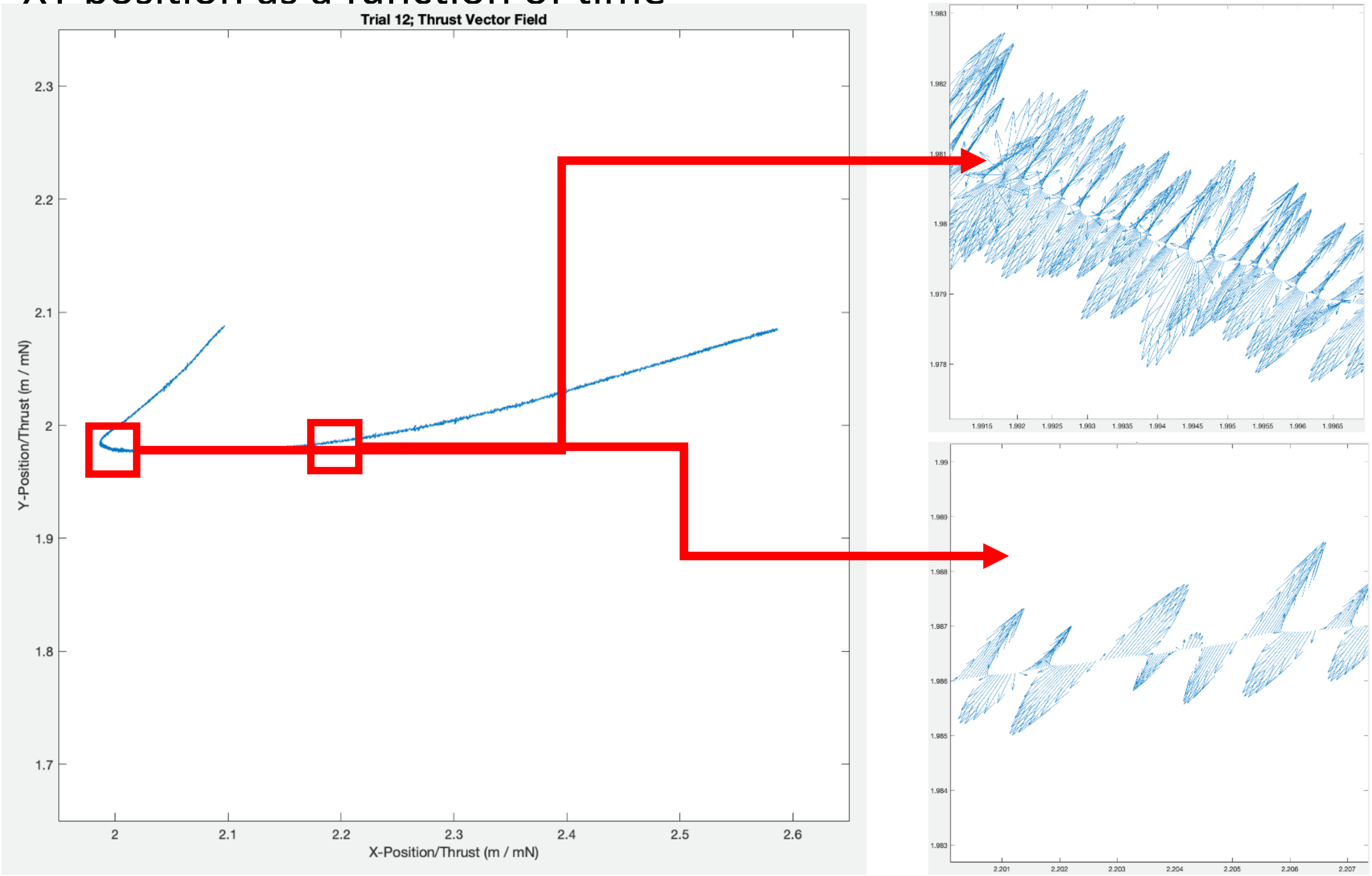


Average magnitude of Force	0.259 mN
Test Duration	3:56
Target Speed	242 RPM
Speed Range	240-233 RPM

Pistons were all taped down, *this will be the "control". Started on near the wall of the pool. Took significantly less Current to operate. Produced significantly less average thrust.*

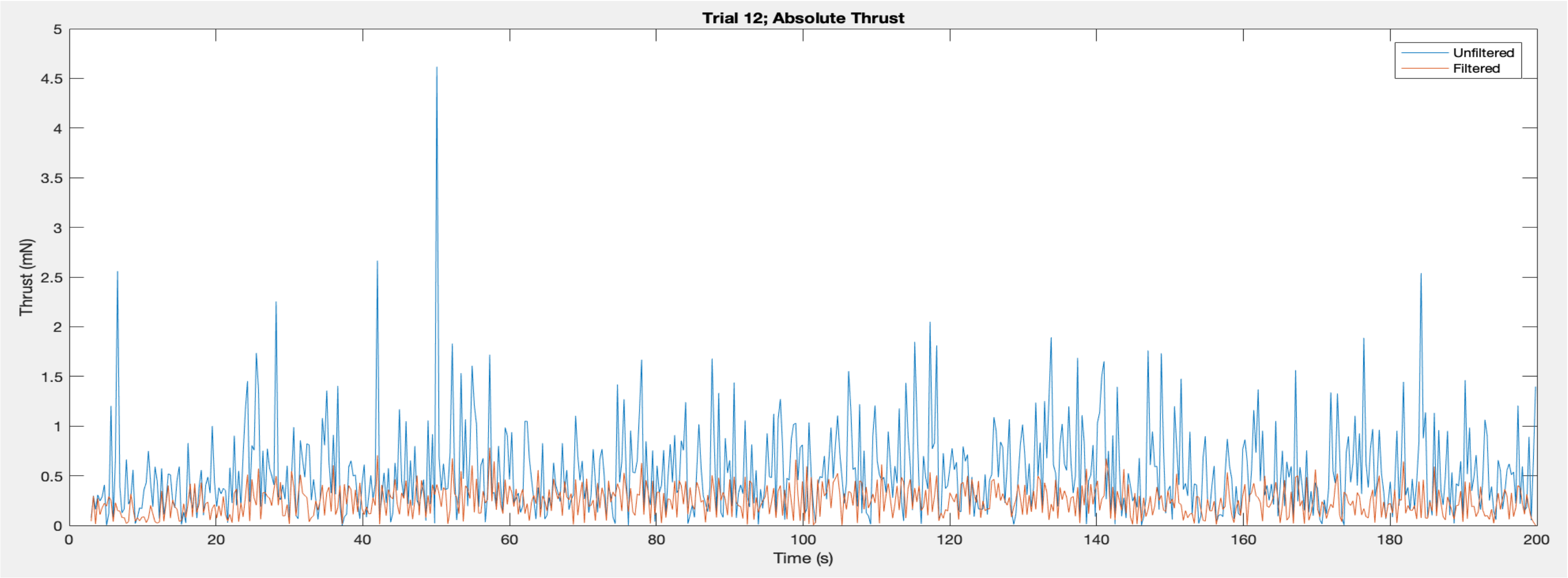
- **Trial 12 5/31/2019 15:45**

XY position as a function of time



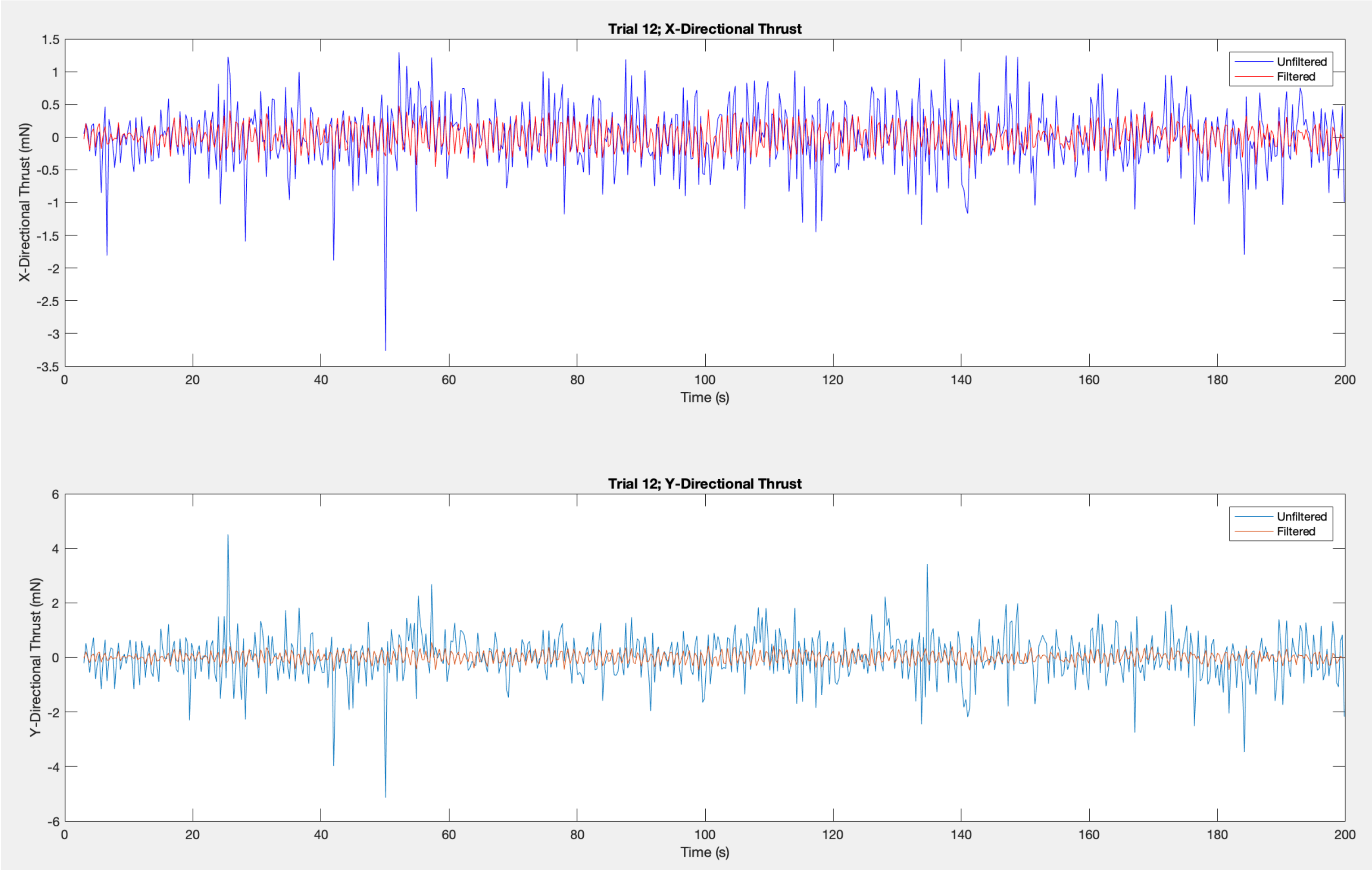
Force Summary

- **Trial 12 5/31/2019 15:45**
  1. Force value obtained: Numerical Differentiation.
  2. Plot Filtering: Moving Mean & Savitsky-Golay Filtering.
  3. **Average Magnitude of Force = 0.295 mN.**



- **Trial 12 5/31/2019 15:45**

1. Force in the X and Y directions.



Phase II Conclusion

Results and Observations

Average **input power is 18.15 W** for about 3 minutes of continuous operation.

Average force magnitude is 4.14 millinewtons (0.00414 N), but **nominal thrust vector could not be ascertained.**

No net linear thrust can be discerned due to the constantly changing direction and magnitude of the thrust vector.

The CID's repeated pattern of curved movement indicates a thrust bias in a certain direction, but the magnitude and direction of this cannot be concluded from this test. Constraining movement in some way may reveal more information in this regard.

General rotational motion of CID in water table indicates there may be a coupling between linear acceleration and the observed spin rates.

Trial 12, having produced a mere average thrust magnitude of 0.295 mN, points to the importance of the magnet "pistons" in regards to thrust production.

Test runs are limited to <10 mins by the CID battery charge capacity.

Wireless input power is in agreement with previously measured data.

Inner four magnet "piston" were susceptible to disassembly after each run due to vibrations, as was the case in Trial 11. Suggested hardware modifications are:

Change cross-head screw to hex

Custom tooling to tighten screws holding pistons in slot

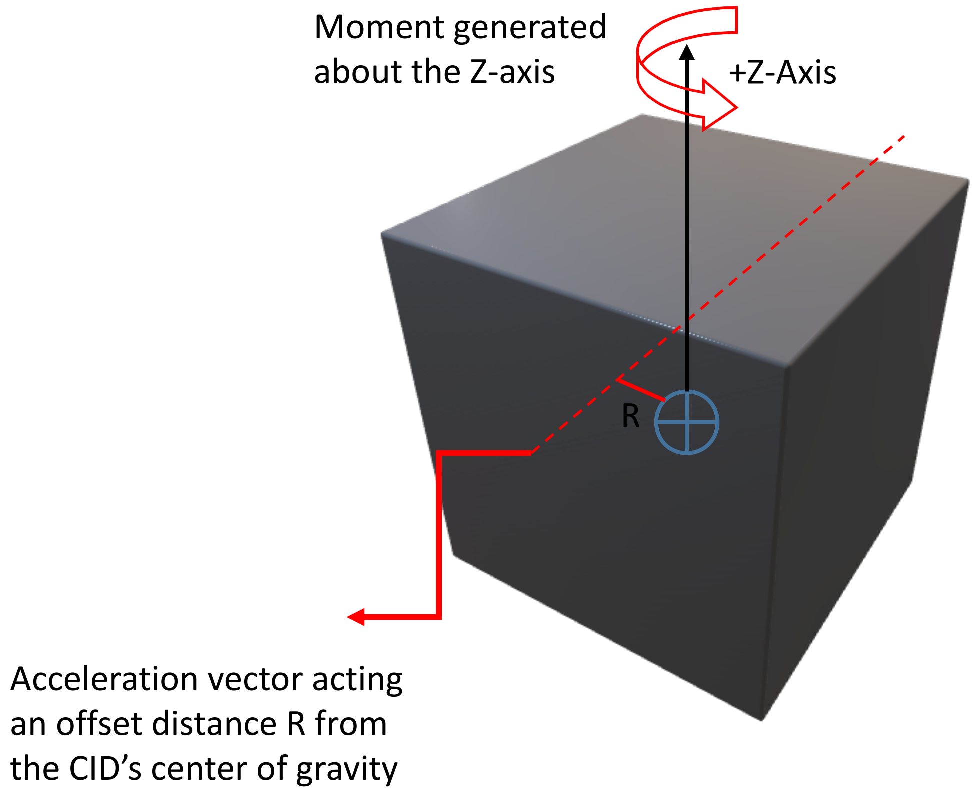
Increase clearance for manual screw adjustment

Results and Observations

- Linear acceleration coupling concept

1. A component of the measured acceleration goes to generating motion about the CID's body-fixed axes

2. Ex: If the acceleration vector acts at an offset distance from the CID's center of gravity, there the acceleration will generate a moment about the body-fixed z-axis



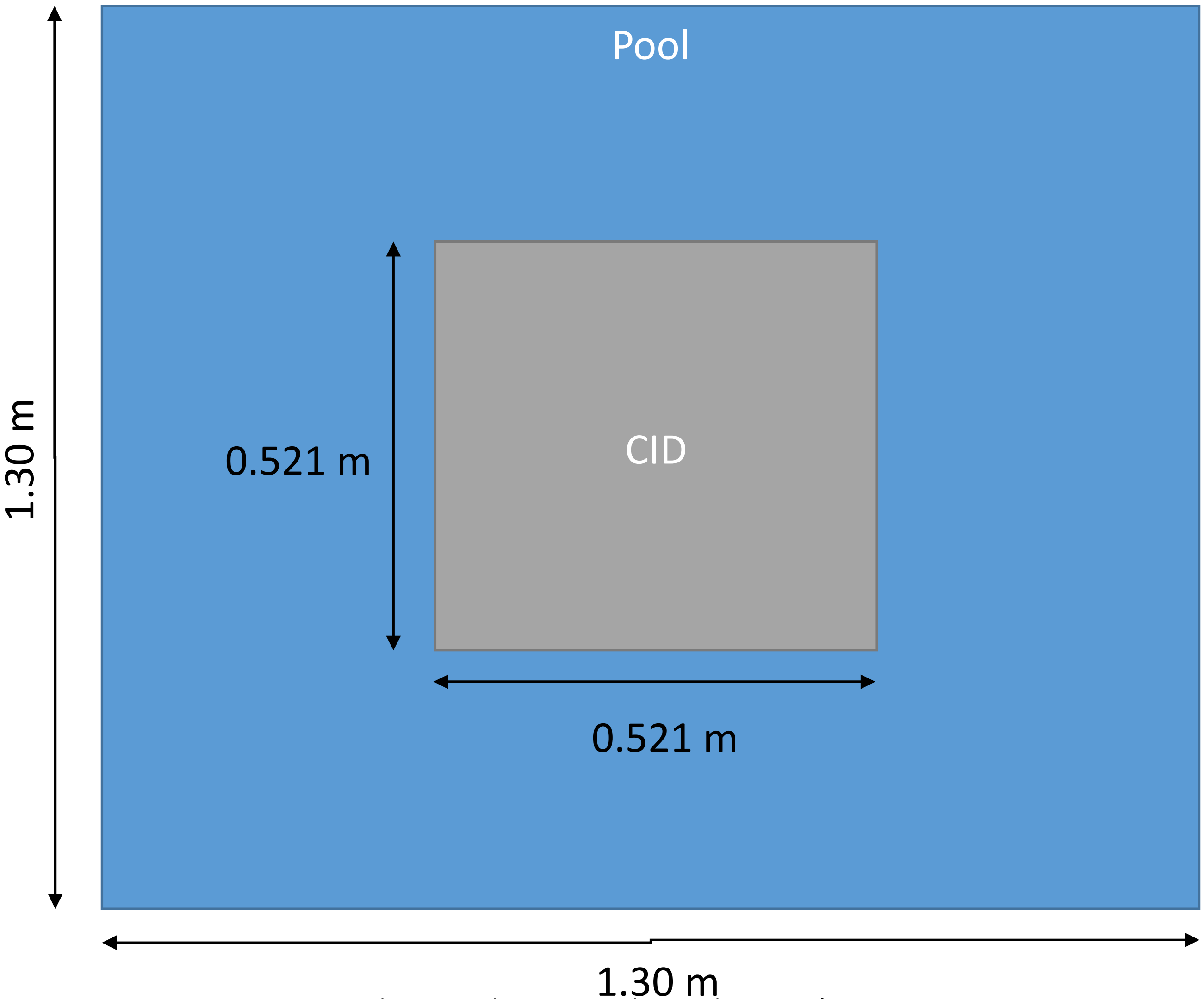
Concluding Slide / Questions?

David R. Jovel, Arega Margousian, Adrian Vicente
Prof. Mitchell L. R. Walker
High-Power Electric Propulsion Laboratory

Back Up

Water Table Planar Motion

- Objective: Visualize planar motion of CID on water table



Travel	Distance
X	0.80 m
Y	0.80 m
Z	0.01 m

Assuming a 66 gal. filled pool:

$$Total\ Water\ Mass = \left(1000\,\frac{kg}{m^3}\right)(0.2498\ m^3) = 249.8\ kg$$

$$Weight\ of\ Pool + CID = (249.8\ kg + 25.1\ kg)\left(9.81\,\frac{m}{s^2}\right)$$

$$Total\ Loading = 2{,}696.77\ N\ (606.26\ lbf)$$

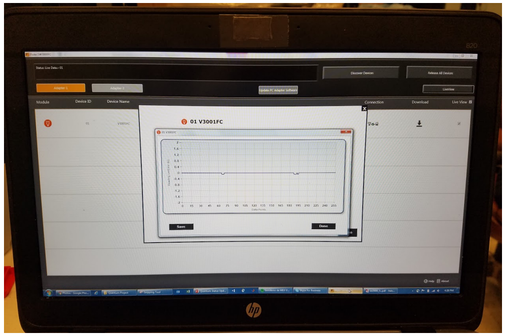
Test Equipment

Current Probe: Fluke a3002 FC Wireless AC/DC Current Meter

- Utilizes Fluke i410/i1010 AC/DC Current Clamp
- Current range: 1 - 400 A DC
- Accuracy: 1%
- Total mass: 1 kg (Clamp + Meter)
- Transmits data to computer

Voltage Probe: Fluke V3001 FC Wireless DC Voltage Meter

- Voltage range DC: 100mVDC - 1000 VDC
- Max DC Volts: 1000 V
- Accuracy: 0.15%
- Total mass: 0.3 kg
- Transmits data to computer



Wireless Transmitter & Software: Fluke Connect sw3000FC

- Fluke software application and laptop USB adapter to collect V/I data via wireless Bluetooth connection
- Mobile App also available

Manual Switch

- Type P/N: Eaton E10E120AS
- Max Current = 6 A
- Purpose: Safety switch / mechanical switch to enable operations

Test Equipment

- **Speed Controller: 65E60-12 – *Dart Controls* battery control**
  - Operating range: 12 – 48 VDC
  - Current range: 0 – 20 ADC
  - Speed adjustment: 5K ohm potentiometer
  - Accuracy: ±1% of base speed
  - Total mass: 1.27 kg
  - Controls speed of CID motor

- **Tachometer**
  - Reading range : 2 – 99,999 RPM
  - RPM Accuracy: ± 0.05%
  - Non-contact laser readings using reflective tape
  - Reads the speed of the CID motor

Electrical Schematic