Code Explanations

This python code is an attempt to combine various aspects of the Eagleworks test stand used to evaluate their EM drive prototype.

A major contention is the use of the superposition of two signals: thermal noise and impulse force. This was outlined in their Figure 5:

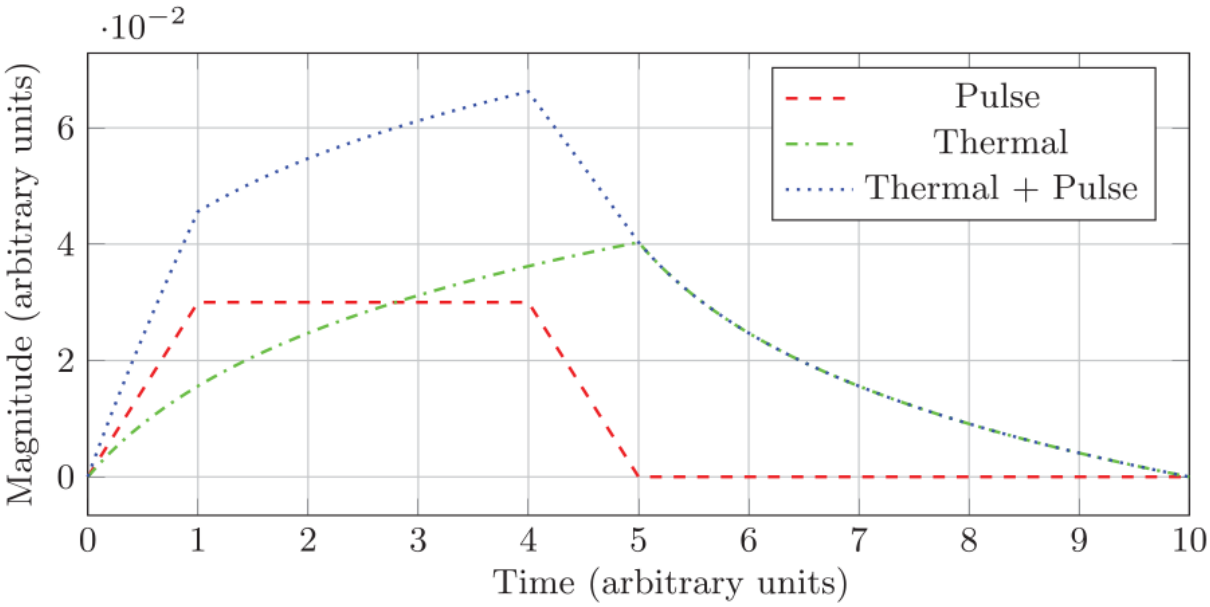

Fig. 5 Superposition of signals: conceptual superposition of an impulsive thrust (red) and thermal drift (green) signal over an on/off power cycle on the torsion pendulum.

There was some difficulty in modeling this response since there was no data presented of what the thermal portion of the curve was. With only the composite result presented it was difficult to work backwards to recreate the signals.

The calibration pulses were used in an attempt to measure any linear jump in forces against the nominal position of the torsion balance. There was also a thermal signal, an assumed impulse force generated by the EM Drive and some noise, which was unquantified in their experiement.

To replicate these calculations and methods, Figure 8. and the corresponding text was carefully analyzed.

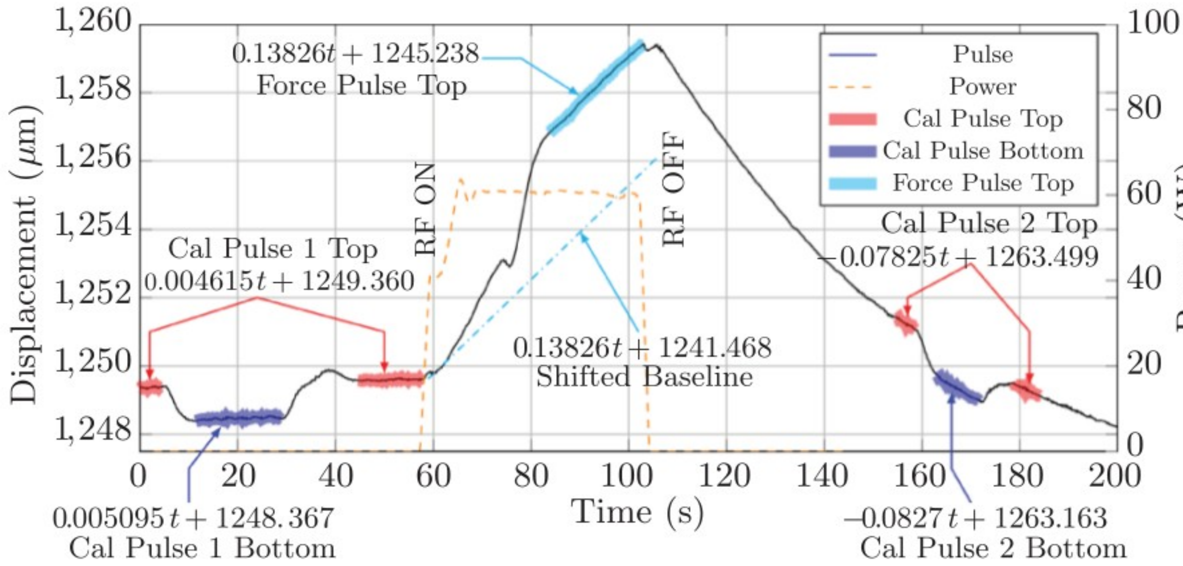

Fig. 8 Force measurement procedure plot: the figure shows one of the 60 W forward thrust runs with the data annotated to indicate the sections used to determine the calibration pulse characteristics and the force pulse characteristics (Cal, calibration).

The resulting simulated signals are shown below with the assumed impulse force, 2 calibration pulses, thermal profile and the total combination of these signals (with some Gaussian noise) scaled to match the values shown in Figure 8.

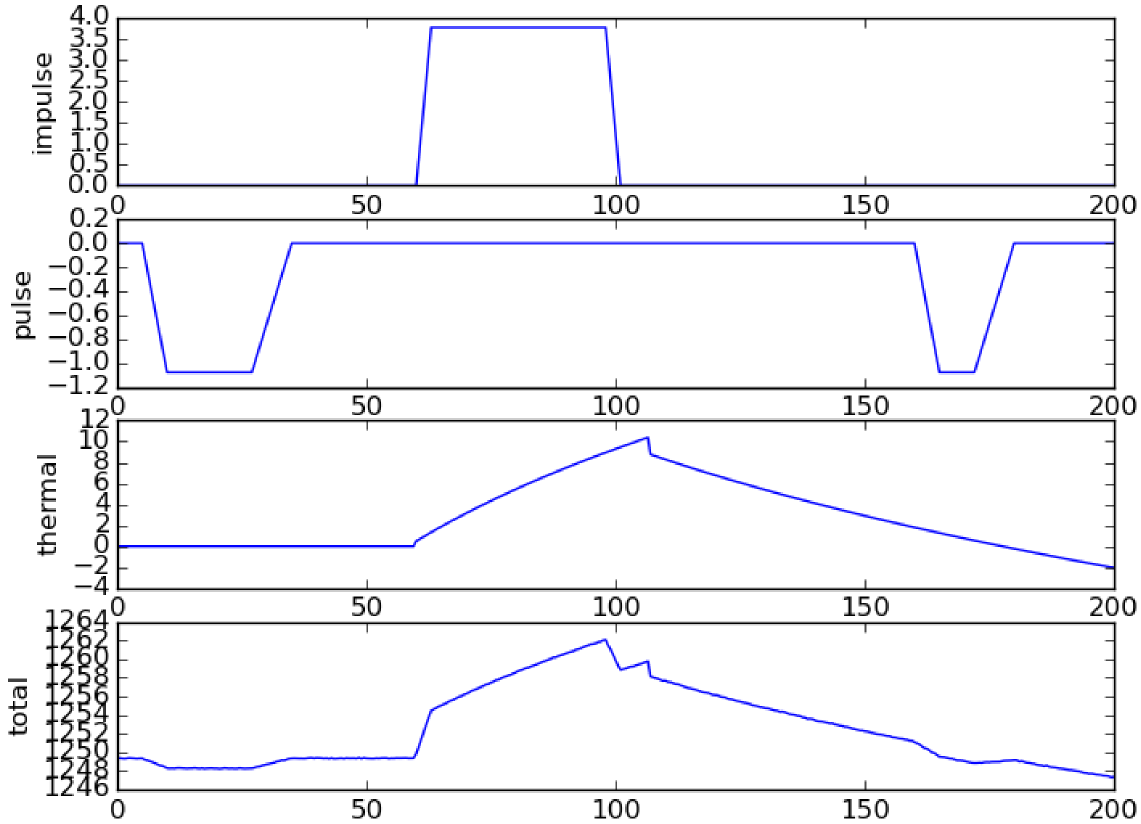

FIGURE A: Signals used for simulation

The same linear regression techniques were used to establish estimates and they are shown on the following diagram with each of their segments highlighted in a different color.

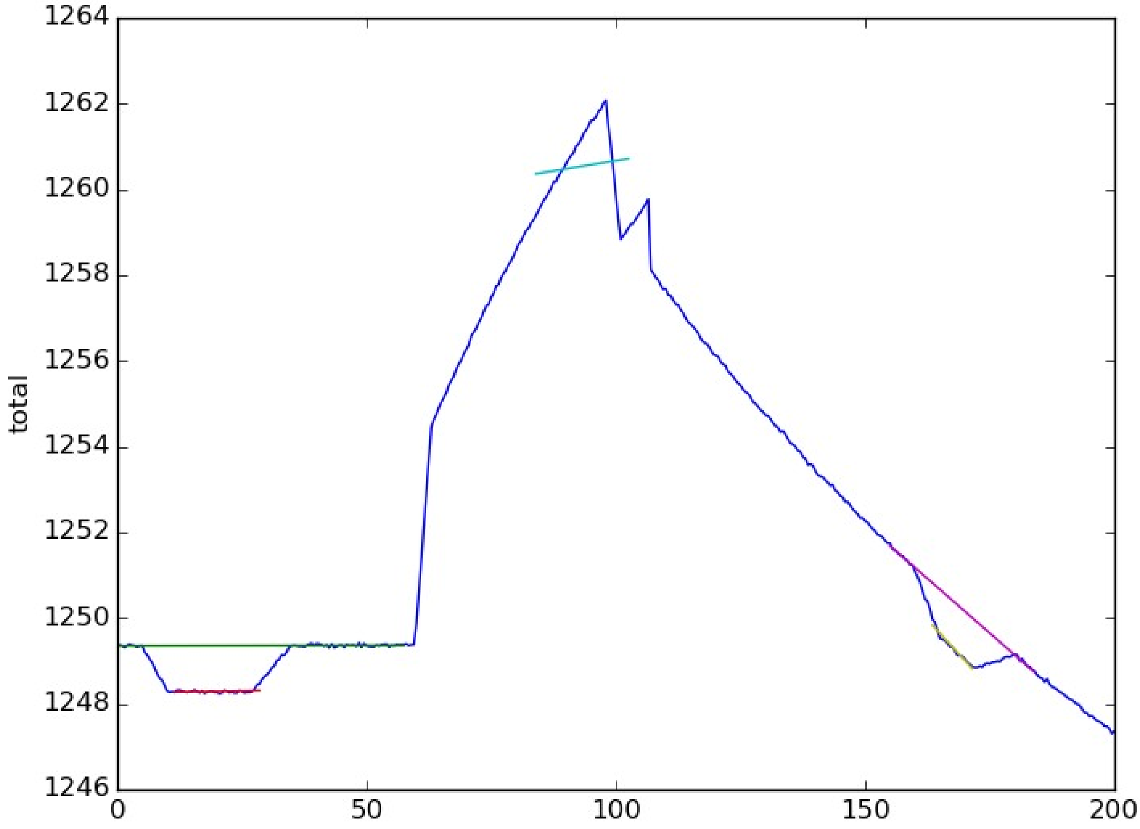

FIGURE B: Analysis of composite signal with linear estimates plotted

The resulting curve fits and force calculations follow:

Pulse 1 Top
m= 0.000199281720898 b= 1249.35454542 r= 0.153395238783 p= 0.378987350365 stderr= 0.000223474536704
Eagleworks: m= 0.004615 b=1249.360

Pulse 1 Bottom
m= 0.00233965835768 b= 1248.24534463 r= 0.252523511584 p= 0.143321722911 stderr= 0.00156057759392
Eagleworks: m= 0.005096 b=1248.367

Pulse 2 Top
m= -0.101838143564 b= 1267.4704713 r= -0.999230888042 p= 2.33817994882e-25 stderr= 0.000969273682573
Eagleworks: m= -0.07825 b=1263.499

Pulse 2 Bottom
m= -0.126786382148 b= 1270.56541839 r= -0.977859188505 p= 1.33548443768e-11 stderr= 0.0070055963548
Eagleworks: m= -0.0827 b=1263.163

Pulse Force
m= 0.0189533282626 b= 1258.77433421 r= 0.111116803606 p= 0.50659437746 stderr= 0.028252488058
Eagleworks: m=0.13826 b=1245.238

CAL1 Pulse Separation:
1.06596518439 um or 31.4475995618 uN force
CAL2 Pulse Separation:
1.07140875332 um or 31.6081931521 uN force
Impulse Force Calculations:
9.41978879458 um or 277.89814368 uN force

The estimate impulse force is way off from the expected 106uN. This was calculated using the Pulse 1 intercept of b= 1249.35454542 and pulse force intercept of b= 1258.77433421, then using their scale factor of dx/df = 0.0338965517 to get ~277.9 uN. Whereas, Eagleworks used 1249.360 (cal1 top intercept) and 1245.238 (pulse intercept). The impulse force curve fit can be improved in simulation by adjusting the time window, however this was not done in order to compare the models as accurately as possible.

Possible Problems:

- The curve fit for the force pulse is the biggest source of error. This can be changed if the time window is modified some, however for this example the numbers were kept the same as reported in Eagleworks paper.
- Thermal curve has a bit of a jump in it when switching directions due to curve fitting one formula to another formula.
- The thermal + impulse superposition in Eagleworks data does not seem to be pulse like, but rather tapers to a lower value as the amplifier stays on. This could simply be a non-linear heating effect, but putting in a pulse model for the force as shown in Figure A produces a composite response that is much higher than what was measured by Eagleworks.
- Matching the data curves was done by hand laying their plots over fine graph paper. This is not an idea way to generate data for curve fitting and leaves room for errors.
- There was no “thermal only” profile measured by Eagleworks, so separating these signals mathematically is difficult.
- The Eagleworks report states different values for dx/df which makes calculations confusing:
  - From EW paper P. 4, the dx vs df is computed based on their statement:
    " 0.983 um, which corresponds with the calibration pulse magnitude of 29 uN"
    which means dx/df = 0.0338965517 m/N
  - On P.5 "two fitted linear equations is 1.078 um, which corresponds with the calibration pulse magnitude of 29 uN."
    which produces dx/df = 0.0371724137931 m/N
- Lack of noise data reported by Eagleworks required just visually estimating their noise response

Improvements

- Try different pulse shapes to better fit their final data
- Access to raw data would improve modeling estimates
- Various values of pulses and pulse shapes could be simulated to estimate the variation and reliability of this measurement technique
- Statistical bounds on accuracy can be established using a wide range of trial runs and simulated impulse signal values
- Fine tuning the numerical windows might provide slightly better approximations of what was shown in Figure 8, however they were strictly followed for this example in an attempt

to duplicate their measurements.

- Thermal model needs some work to mimic their response, however without having a thermal only response to compare it too, this might never be possible.
- Obviously in Figure B vs Eaglework's Figure 8 there is a significant difference in the trailing edge of the pulse drop which changes the linear estimates drastically. As mentioned before the speculation is the lack of change in Figure 8 could be due to the “impulse” force lessening or the thermal heat starting to saturate producting less force before the amp is shut down.
- General code improvements are needed as well