# What can we learn from measuring contaminants on recirculation filters?

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# Goal of Project

The goal of this project was to determine if samples taken from recirculation filters could determine the source of contaminants for an air quality incident. In particular, the goal was to determine this approach could be used to determine if engine lubricating oil was the contaminant that generated the event.

Along the way, a lot of interesting information was found but the above goal always drove the investigation.

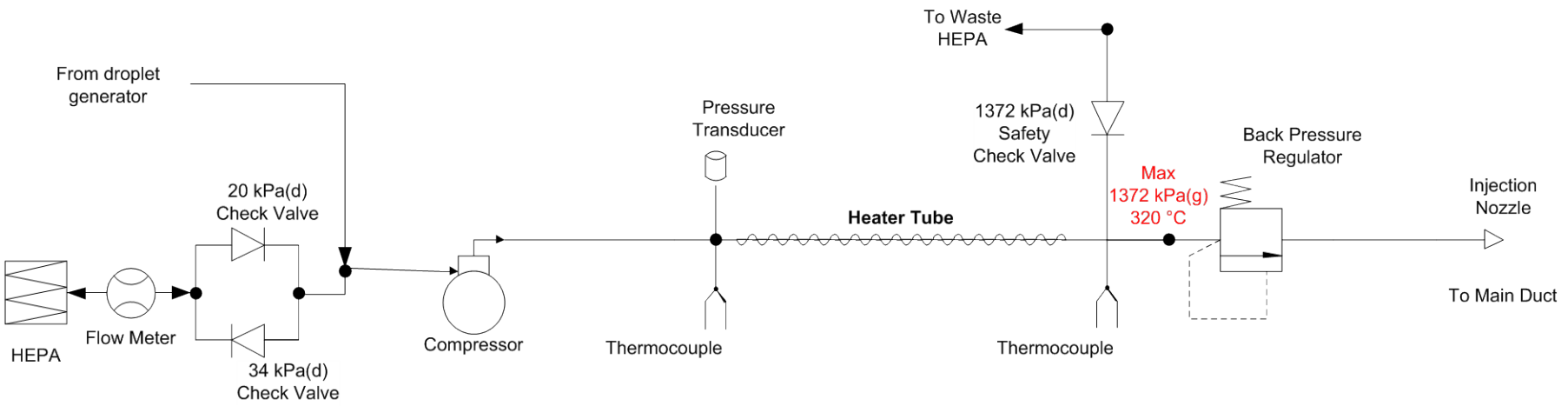
# Project Tasks

- Sampling HEPA filters
  - 110 ***used*** filters received from a variety of sources
    - Service life was not reported
    - Not from “problem” aircraft
    - Variety of samples taken from filters for analysis
  - 97 ***non-standard*** filters received for analysis
    - Service life not reported but filter was removed for analysis so shorter than typical filter
    - Reason for removal was not reported with filter
    - Variety of samples taken from filter for analysis
- Bleed Air Simulator (BAS)
  - Detection limit testing with both with heated and unheated simulated bleed air.

# GC/MS Oil Calibration

- Four TCP compounds (M-TCP, P-TCP, Unk1-TCP, and Unk2-TCP) and peaks associated with the synthetic esters were identified in the jet oil as potential markers.
- BAS simulation was used to investigate potential shifts in TCP concentrations with pressure and temperature
- Final step was chemical analysis of used filters.

# BAS-System




| Simulated mode of aircraft engine operation | Pressure kPa | Temperature $^{o}C$ |
|---|---|---|
| Initial descent from cruise | 200 | 185 |
| End of descent | 460 | 230 |
| High- to low-pressure switchover | 480 | 280 |
| Cruise | 690 | 250 |
| Top climb | 690 | 310 |

# Bleed Air Simulator

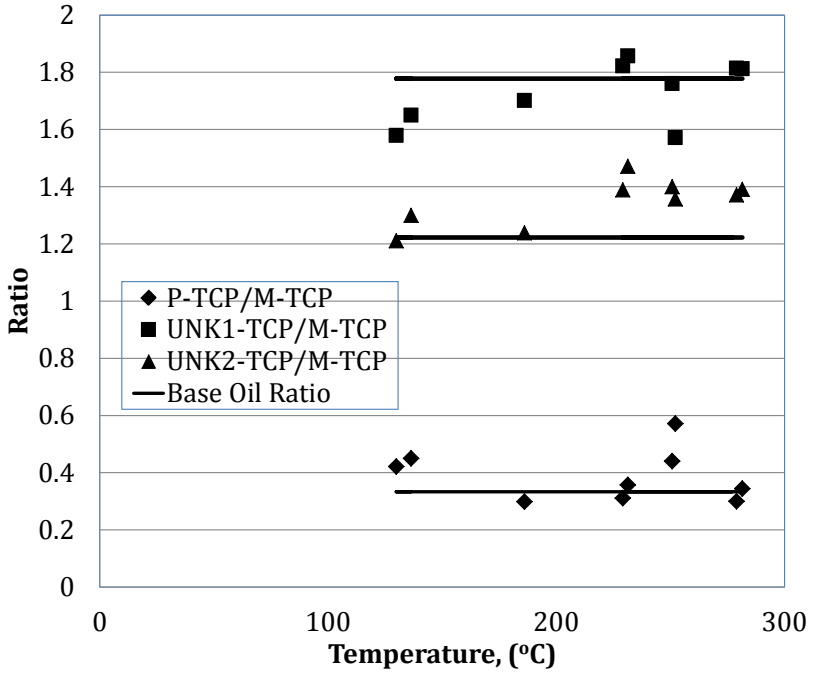
# BAS-System

- Range of BAS pressures and temperatures simulated. All temperatures at high and low pressure.

| Low Pressure | | High Pressure | |
|---|---|---|---|
| Pressure kPa | Temperature °C | Pressure kPa | Temperature °C |
| 200 | 130 | 680 | 230 |
| 200 | 185 | 680 | 250 |
| 200 | 230 | 680 | 280 |
| 200 | 250 | 680 | 280 |
| 200 | 275 | 680 | 310 |

# BAS-System

- Ratio of TCP concentrations obtained.
- Relatively constant with temperature change
- No change with pressure
- Heating does not shift TCP concentration in sampled particulates



# Filter Analysis

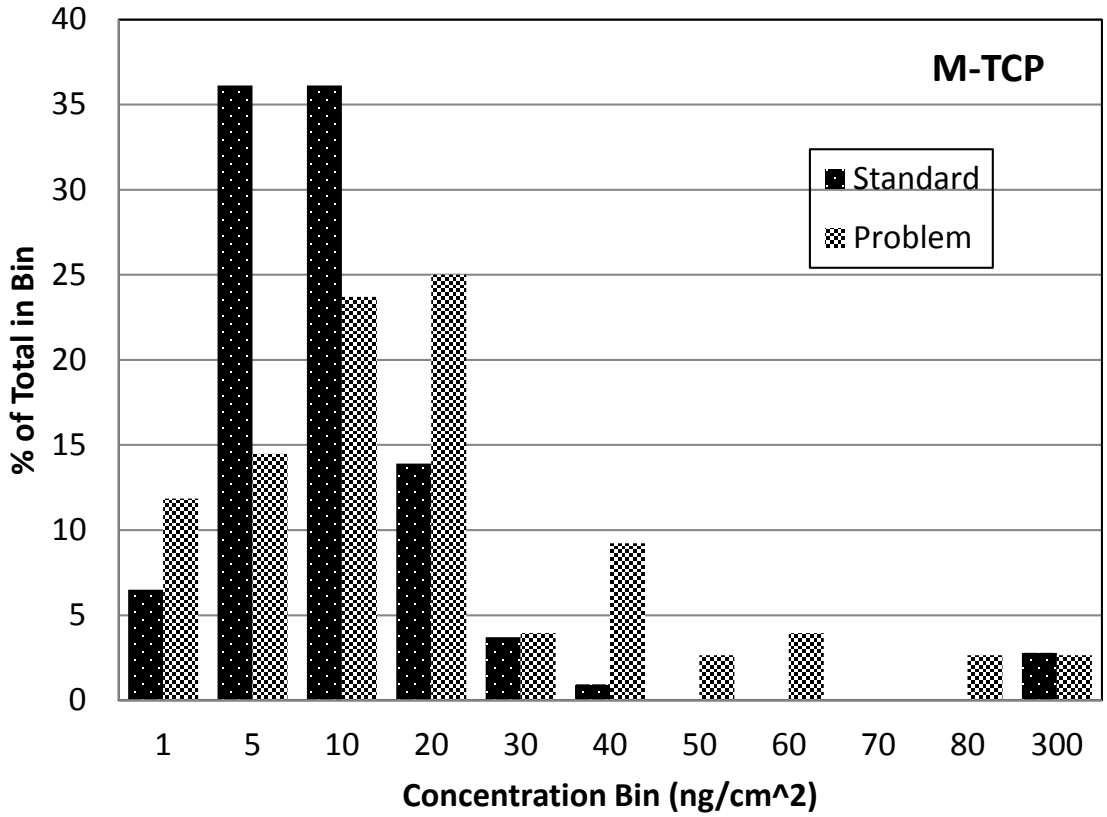
- M-TCP found in 95% (std) and 89% (non-std) of filters
- Synthetic lubricant markers found in 4% (std) and 31% (std) of filters.
- Presences of all four TCP markers more strongly correlates with lubricant markers.

| | Standard Filters | Nonstandard Filters |
|---|---|---|
| Presence of M-TCP | 95% | 89% |
| Four TCP markers | 28% | 45% |
| Synth. lub. marker | 4% | 31% |
| Both markers | 3% | 30% |

# Filter Analysis

| | Standard Filter | Non-Standard Filters | T-Test |
|---|---|---|---|
| **M-TCP** | 11.5 ng/cm$^2$, STDev = 27 | 23.5 ng/cm$^2$, STDev = 48 | p=0.053 |
| **Unk1-TCP** | 13.6 ng/cm$^2$ , STDev = 37 | 29.2 ng/cm$^2$, STDev = 58 | p=0.04 |
| **Unk2-TCP** | 4.8 ng/cm$^2$ , STDev = 18.9 | 12.9 ng/cm$^2$ , STDev = 29 | p=0.033 |
| **P-TCP** | 0.7 ng/cm$^2$ , STDev = 2.8 | 1.7 ng/cm$^2$ , STDev = 3.7 | p=0.123 |

# Filter Analysis



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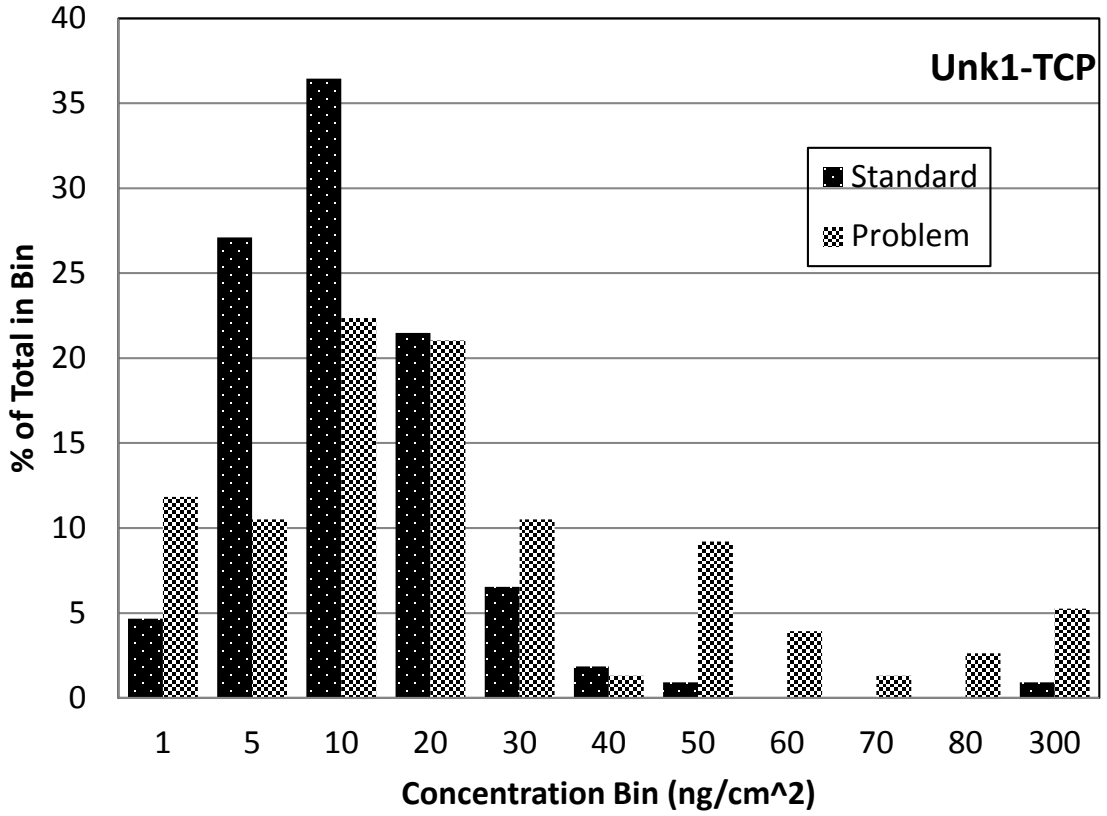

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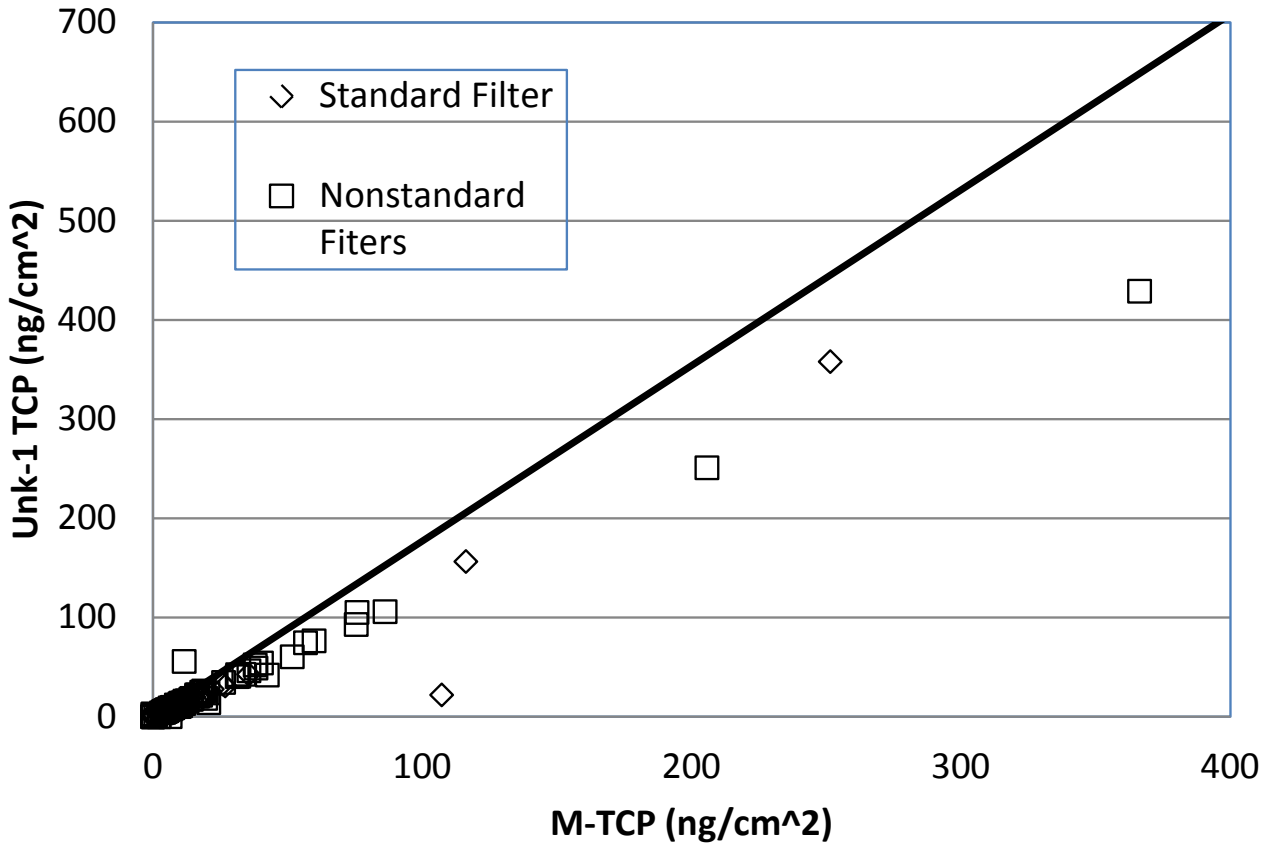

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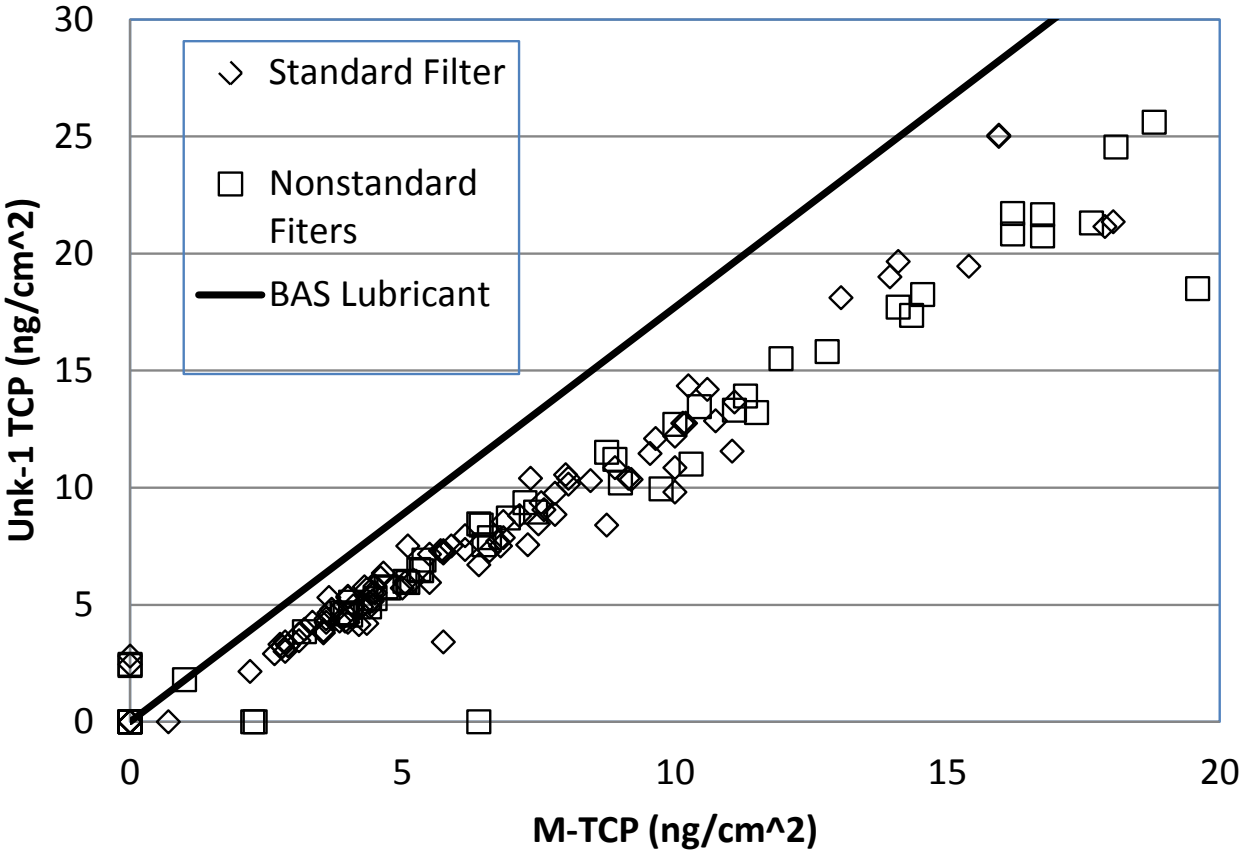

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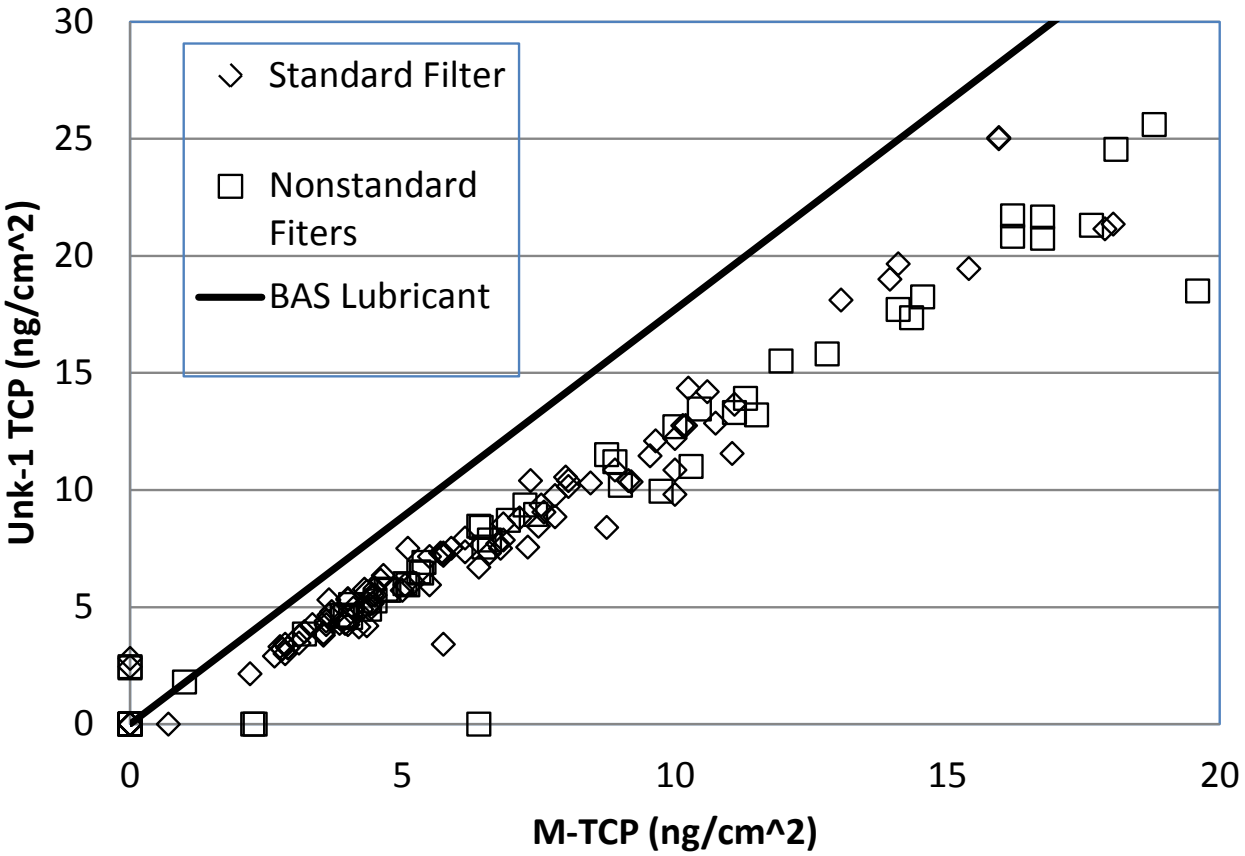

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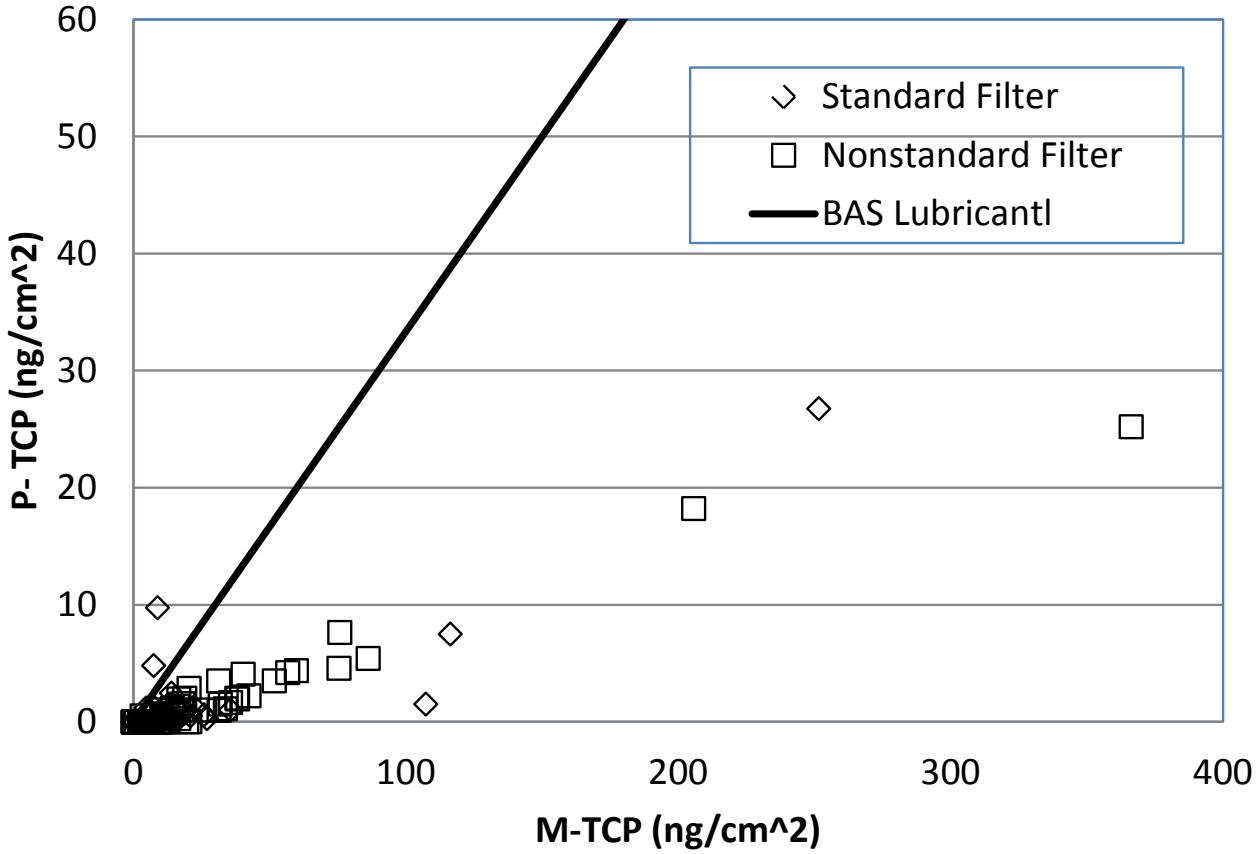
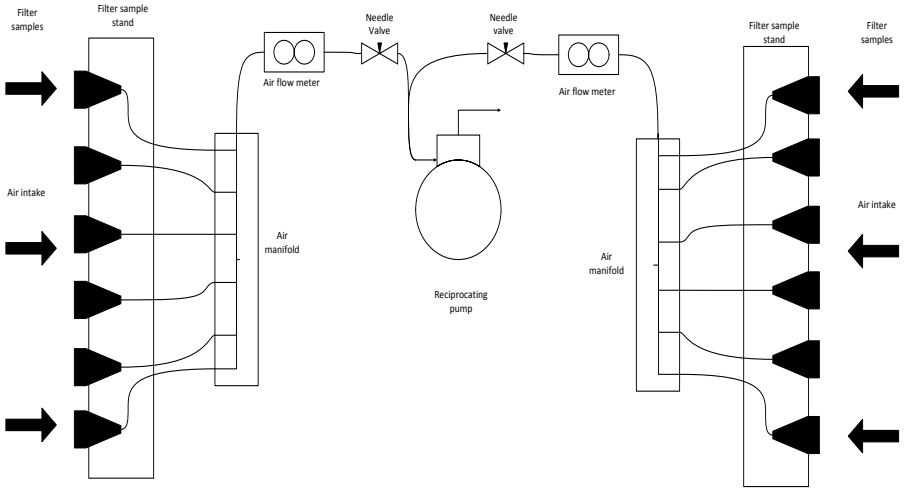


# Long Term Persistence Study Results

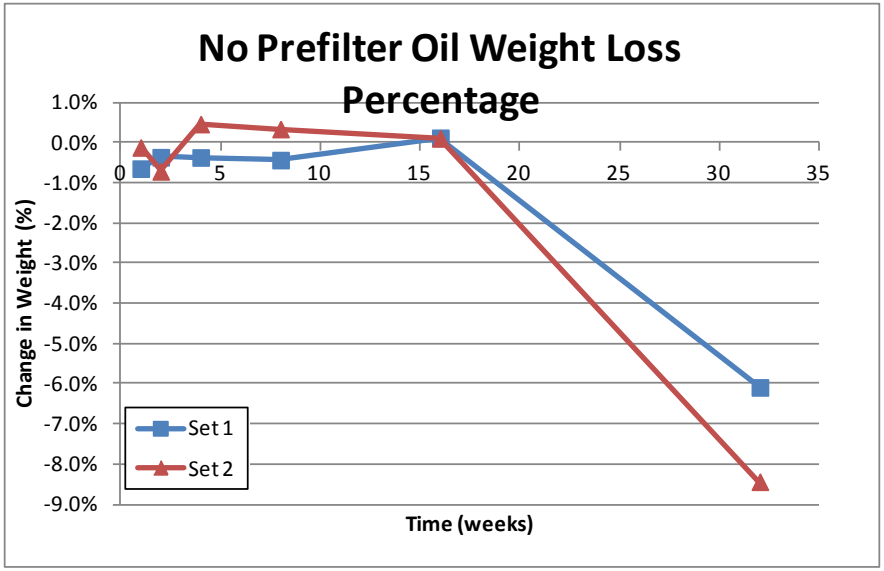
- How long can we expect oil contamination to remain on the filter material?
- Doped oil samples were exposed to a representative air flow rate over an expected service life.
- Oil samples were weighed before and after exposure.
- GC/MS testing was performed after the exposure and to control samples.

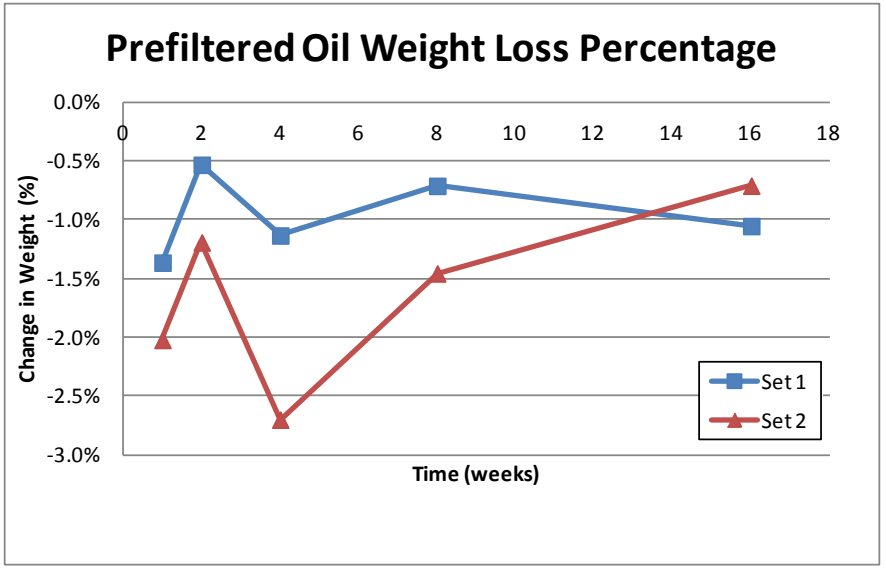
# Test Setup

- Exposure time: 0, 1, 2, 4, 6, 8, 16, 32 weeks
- Two independent samples at each time
- Flow rate set to match Pall HEPA filter: 5 CFH/in$^2$
- Ambient temperature from 20 to 30 °C

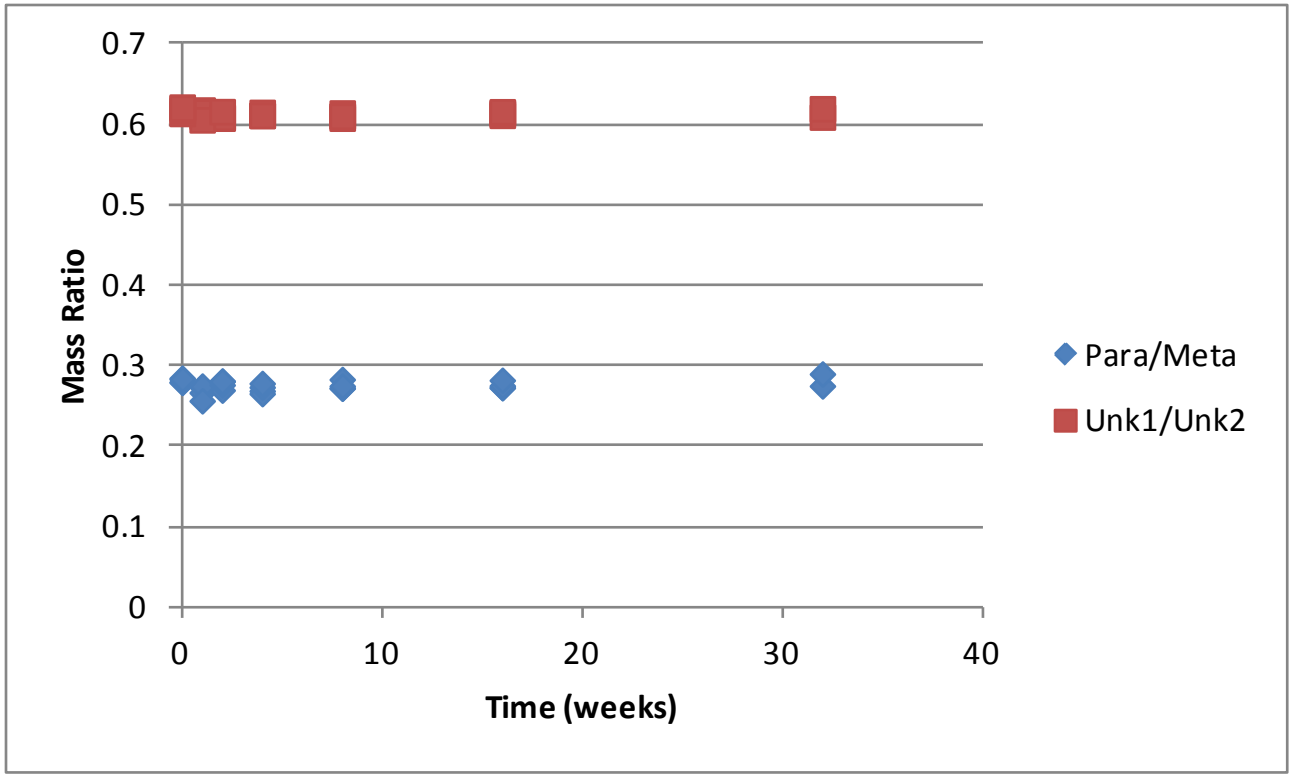


# Gravimetric Results

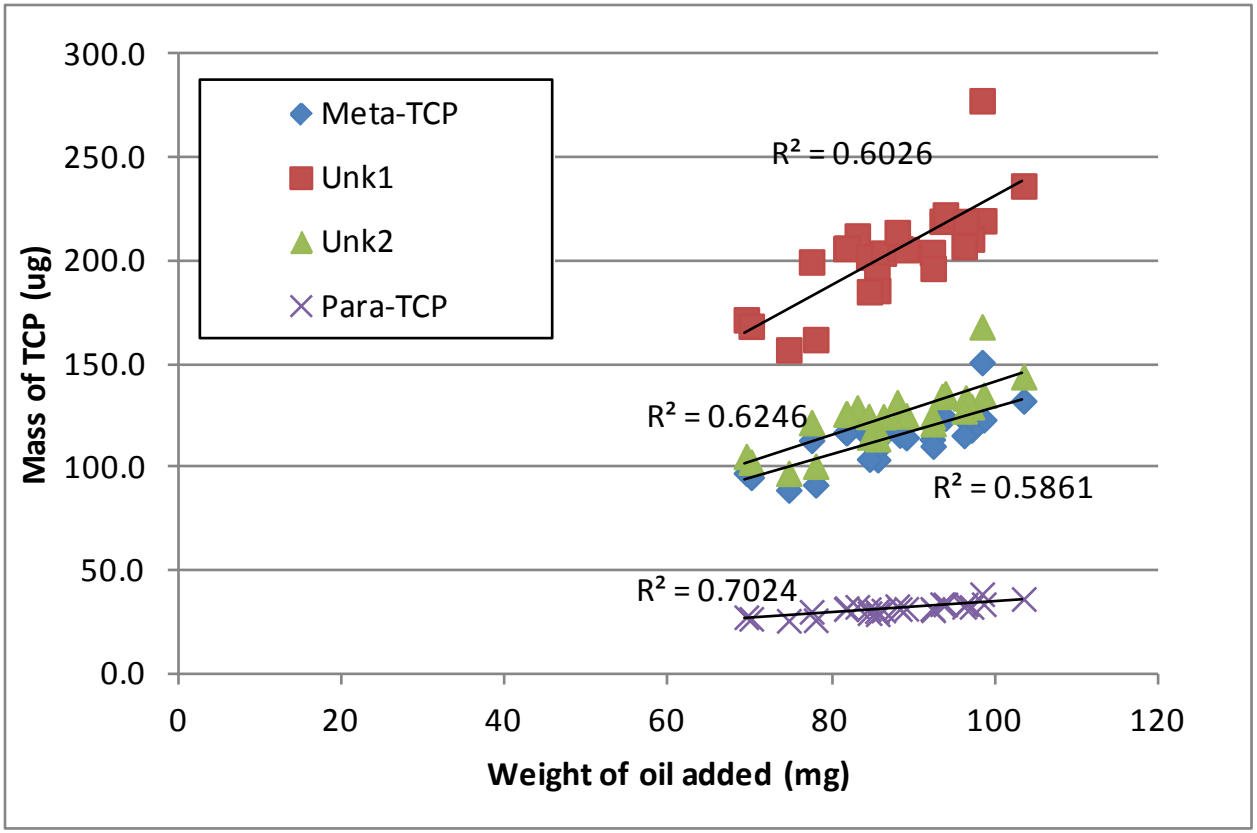


# GC/MS Results



# Correlation with Oil Added



# Conclusion

- A single TCP marker is present on a majority of filters.
- An oil signature is only present in a small fraction of standard filters but is present on a much larger fraction of the non-standard filters.
- Synthetic oil appears to be the best marker for oil presence.  All four TCPs combined may also be a good marker.
- A single TCP isomer is not a reliable marker.
- Oil on filters is long-lived and provides an integrated sample and is not restricted to recent flights.