Evaluating Line Illumination Sampling of a Handheld Raman Spectrometer for Detecting Hydraulic Fluid Contamination in Jet Fuel

Megan Linson, BS*; Javier Hodges, BS; Jorn Yu, PhD

Department of Forensic Science, Sam Houston State University, Huntsville, TX 77340

Sam Houston State University

ABSTRACT

This study compares two handheld Raman spectrometers with different laser sampling designs for detecting hydraulic fluid contamination in five jet fuels. Six hydraulic fluids of varying chemical bases were evaluated, and spectra were analyzed using PCA to assess clustering and instrument performance.

INTRODUCTION

Handheld Raman spectrometers are increasingly used for rapid, nondestructive chemical screening, yet their performance is strongly influenced by laser sampling design. The Powell lens with line illumination sampling spreads the laser across a wider area to enhance spectral detail, whereas Orbital Raster Scan (ORS) with rapid laser spin (RLS) sampling rotates the beam to simplify acquisition, potentially affecting resolution and sensitivity in complex matrices such as jet fuel. Detecting hydraulic fluid contamination in jet fuels is operationally significant, making it important to evaluate how these sampling strategies perform across different fuel types and fluid chemistries. This study compares two handheld Raman spectrometers using line illumination and RLS sampling to assess their ability to detect six hydraulic fluids across five jet fuels under standardized acquisition conditions. Overall, these findings highlight the importance of selecting appropriate sampling designs and accounting for device-specific performance when using portable Raman tools for fuel contamination screening.

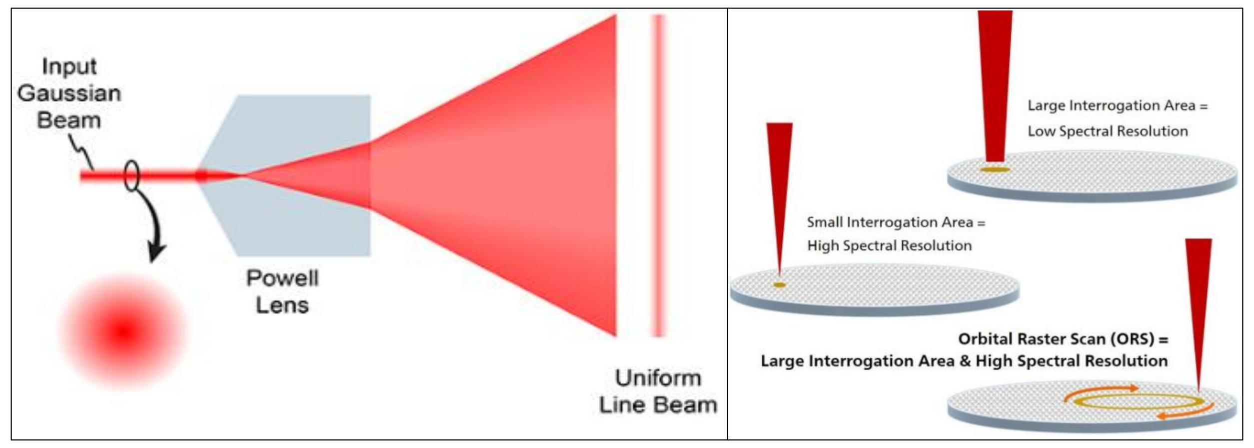

Figure 1. *The Powell lens with line illumination sampling (left) is compared to Orbital Raster Scan with rapid laser spin sampling (right).*

MATERIALS & METHODS

Raman Instrument	Sampling Type
Wasatch Photonics WP-785XSB-ILP	Line Illumination
Ocean Optics IDRaman Mini	Rapid Laser Spin

Jet Fuel Sample	Origin
Paragon Reference Sample	LGC
Conroe Jet A Fuel	Conroe Airport
R Jet Fuel (Merox)	Marathon Petroleum Company LP
Jet Fuel (Triple)	Marathon Petroleum Company LP
Straight Run Jet Fuel	Marathon Petroleum Company LP

Hydraulic Fluid Sample	Origin	
MIL-PRF-87257C	Radcolube	Synthetic
MIL-PRF-83282D	Lanxess X Royco	Synthetic – PAO Additives
MIL-PRF-5606H	Lanxess X Royco	Petroleum - Mineral Oil-based
MIL-PRF-87252C	Castrol	Synthetic – PAO Additives
HyJetIV-A	Mobil	Phosphate Ester Based
MIL-PRF-5606J	AeroShell	Petroleum - Mineral Oil-based

RESULTS & DISCUSSION

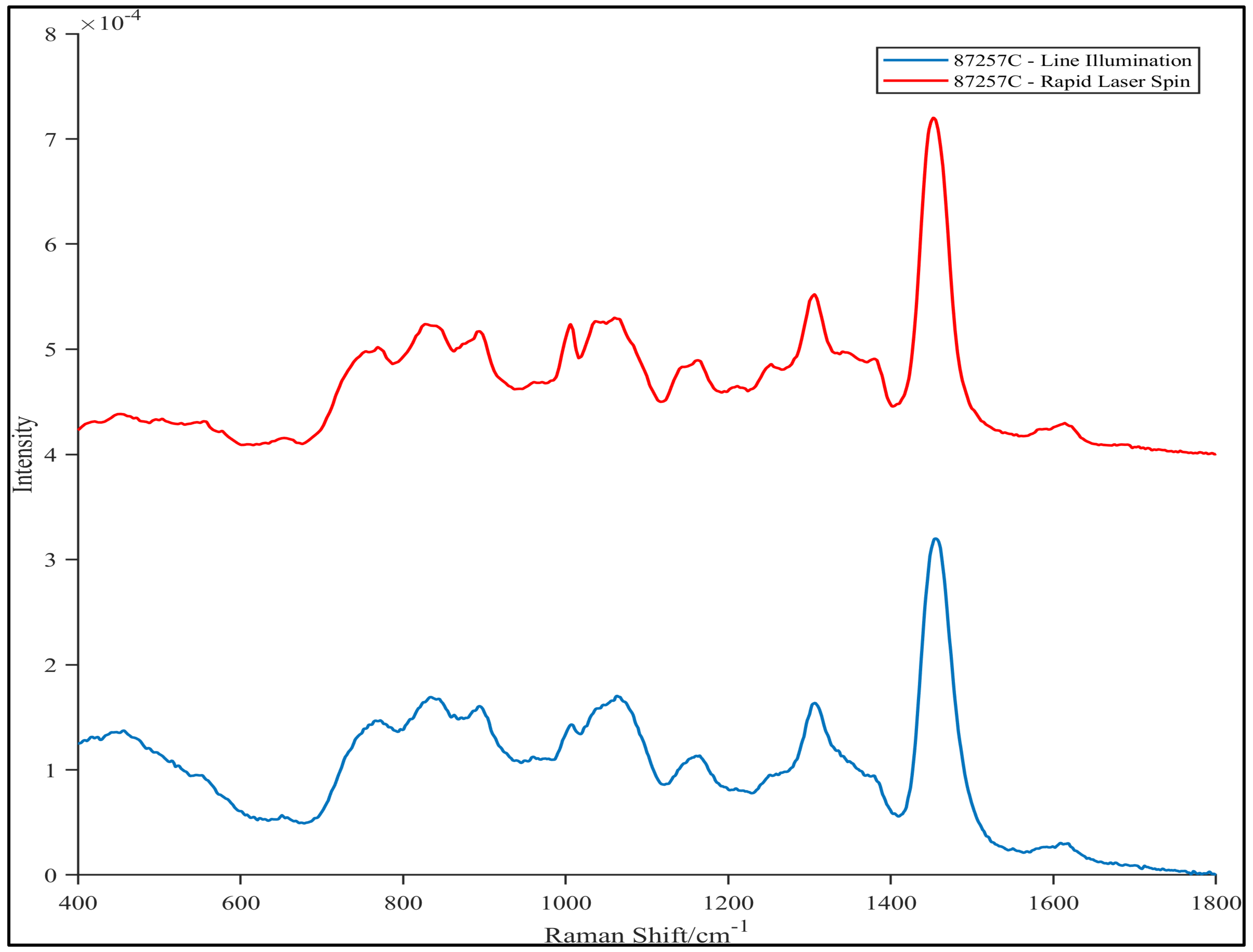

Figure 2. Paragon jet fuel with 1% hydraulic fluid 87257C using line illumination sampling (bottom) and rapid laser spin sampling (top)

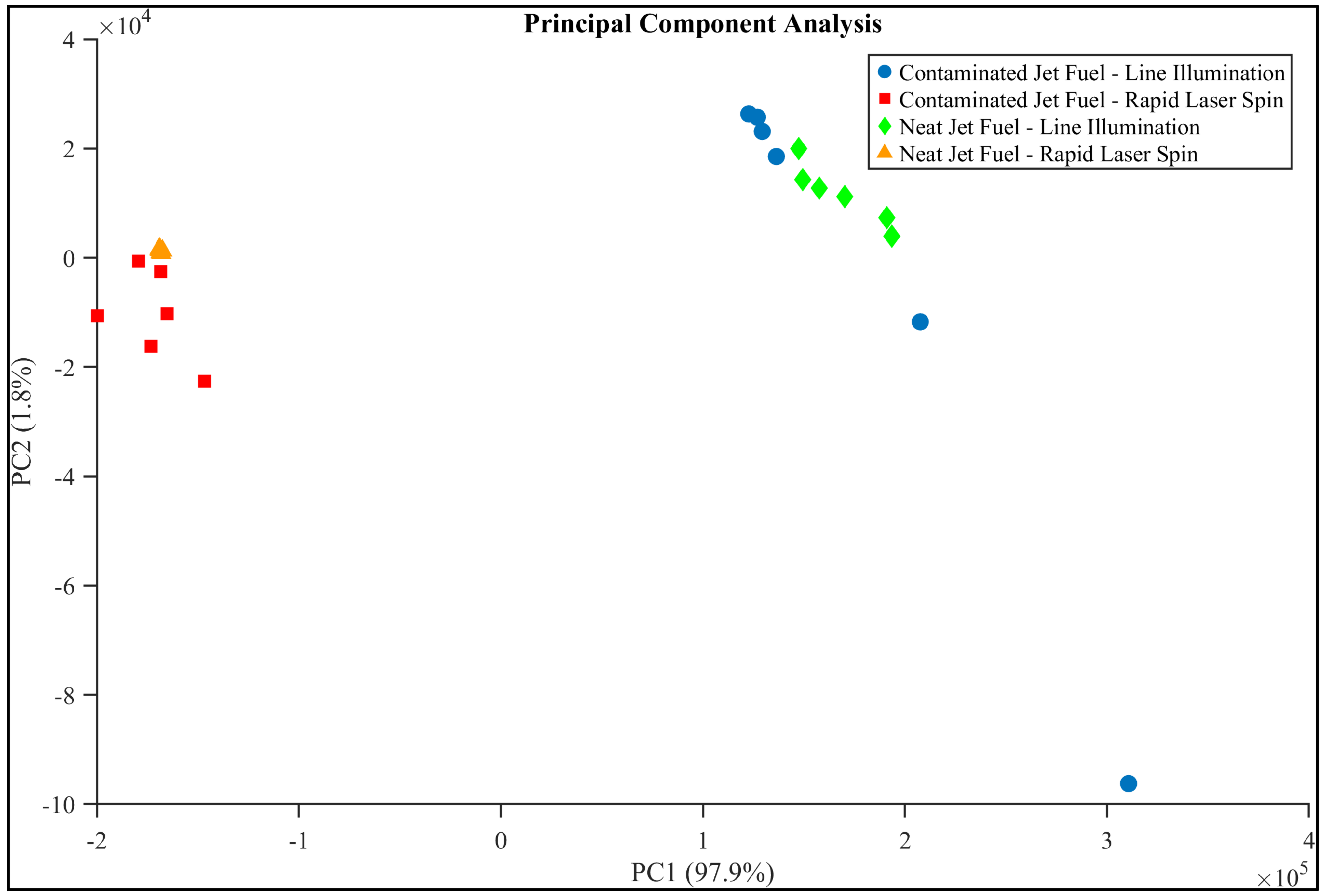

Figure 3. Principle Component Analysis (PCA) plot comparing line illumination and rapid laser spin sampling

Line Illumination Sampling:

- Line Illumination spectra showed sharper and more intense Raman peaks, particularly in the 1350–1650 cm^{-1} aromatic/alkyl stretching region, compared to the RLS system.
- Uniform line illumination reduces localized hot spots and distributes laser power evenly across the sample, increasing effective laser–sample interaction and improving signal consistency.
- Variability within each fuel group was consistently detectable, with small shifts in band shape and magnitude retained across replicates.

Principle Component Analysis:

- PCA revealed clear separation between instruments analyzing the same Paragon jet fuel samples.
- Line illumination produced wide score dispersion along PC1 and PC2, reflecting higher spectral variance and increased analytical sensitivity.
- The two datasets formed non-overlapping clusters, demonstrating that the instruments' spectral outputs are not interchangeable without calibration.

REFERENCES

1. Hodges, J.E.; Marchand, K.; Monjardez, G.; Yu, J.C.-C. The Classification of Synthetic- and Petroleum-Based Hydrocarbon Fluids Using Handheld Raman Spectroscopy. Chemosensors 2025, 13, 327. https://doi.org/10.3390/chemosensors13090327
2. Wasatch Photonics. *WP Raman XSB Series: Ultracompact Raman for Nonuniform & Biological Samples*; WP-PS_WP-Raman-XSB-Series_RevA; Wasatch Photonics: Durham, NC.
3. Ocean Optics, Inc. *IDRaman Mini: Handheld Raman System Installation and Operation Manual*; Document No. 000-40000-010-02-201311; Ocean Optics: Dunedin, FL, 2013.
4. "What Is a Powell Lens?" *Coherent*, Coherent, 7 July 2025, www.coherent.com/news/glossary/powell-lens.

CONCLUSIONS

This study demonstrates that laser sampling geometry strongly influences handheld Raman performance for detecting hydraulic fluid contamination in jet fuel. Line illumination produced sharper Raman features, preserved fuel-specific spectral signatures, and exhibited greater variance in PCA, indicating increased sensitivity to subtle compositional differences. In contrast, rapid laser spin sampling showed reduced spectral variance and tightly clustered PCA scores, limiting its ability to discriminate complex mixtures. These findings highlight that Raman data acquired from different handheld systems are not directly interchangeable without calibration and underscore the importance of selecting sampling designs optimized for sensitivity when performing field-based fuel contamination screening. Understanding these performance differences is critical for forensic, aviation, and military applications where rapid and reliable fuel assessment is required. Future work will focus on evaluating detection limits and expanding mixture complexity to further assess field applicability.

ACKNOWLEDGEMENTS

Support for this project was provided in part by U.S. Air Force Contract No. FA810024C0003 through the U.S. Department of Defense. The interpretations and conclusions in this presentation are solely those of the authors and do not reflect official positions of the Department of Defense.

FSF FORENSIC SCIENCES FOUNDATION

EMERGING FORENSIC SCIENTIST AWARD

Department of Forensic Science
College of Criminal Justice
forensics.shsu.edu