

Introduction

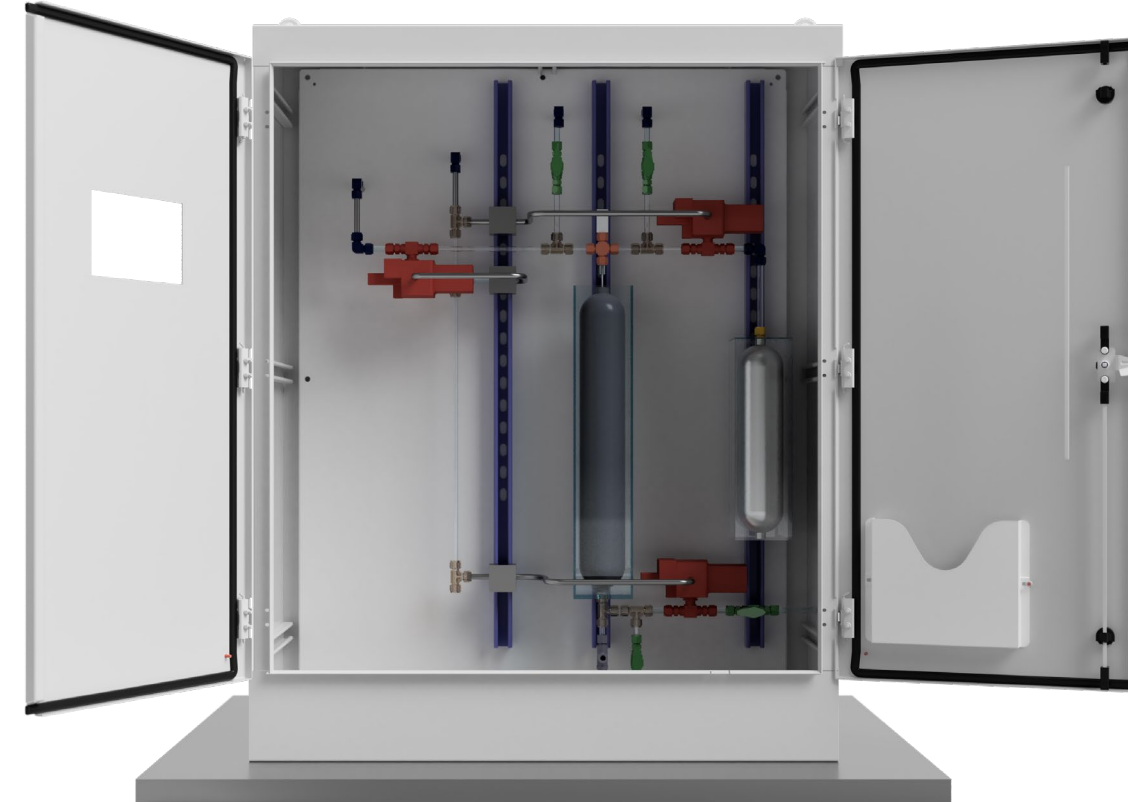
The effectiveness of fire suppression systems is critical for protecting both human life and military equipment in confined environments. Aberdeen Test Center (ATC) conducts the Crew Compartment Halon Alternate Agent Program at Aberdeen Proving Ground to identify alternatives to Halon 1301, an ozone-depleting fire suppressant with high global warming potential (Polyanski et al., 1997). To support this effort, ATC developed a Fireball Generator to simulate fireball events by atomizing JP8 fuel, igniting it, and evaluating the suppression effectiveness and safety of the alternate agent being tested (Kogut et al., 2019). However, due to aging, the Legacy Fireball Generator (LFBG) has decreased in both fire strength and reliability. A previous attempt to develop a Modernized Fireball Generator (MFBG) was discontinued when key personnel left before completion.

The K_{st} value (bar·m/s), a measure of explosion severity, is calculated using the maximum derivative of the pressure–time curve multiplied by the cube root of the enclosure volume (m^3) (Fumagalli et al., 2016). The legacy application used to analyze K_{st} was difficult to navigate due to a cluttered interface and relied on an inaccurate calculation method. The purpose of this project was to modernize a fireball generator with improved strength and reliability and to develop a user-friendly application for efficient and accurate K_{st} calculation including features not present in the legacy application such as data and graph export and the option to start graphs at the ignition point of the explosion.

Methods and Materials

The MFBG was designed in Autodesk Fusion using CAD drawings of purchased components (Figure 1). The system uses a 304 L stainless steel fuel tank to store and heat fuel, which is then sprayed through a 10–30 ft tube and a multi-hole nozzle to improve combustion.

Figure 1 (right): A render from Autodesk Fusion of the MFBG model. The enclosure is measured to be 60 in. × 48 in. × 18 in.



With ATC’s legacy application, rather than taking the true maximum derivative as defined in the standard K_{st} calculation, it calculates the slope between two judgement-based selected points, reducing accuracy. A modernized version of ATC’s application named the K_{st} Analyzer was developed to automatically determine the maximum derivative from the pressure–time curve to accurately calculate K_{st} .

Methods and Materials (continued)

The K_{st} Analyzer (Figure 2) was created in Visual Studio .NET using Avalonia UI (C#) to provide a modern desktop GUI, interactive charting and automated calculations with large datasets.



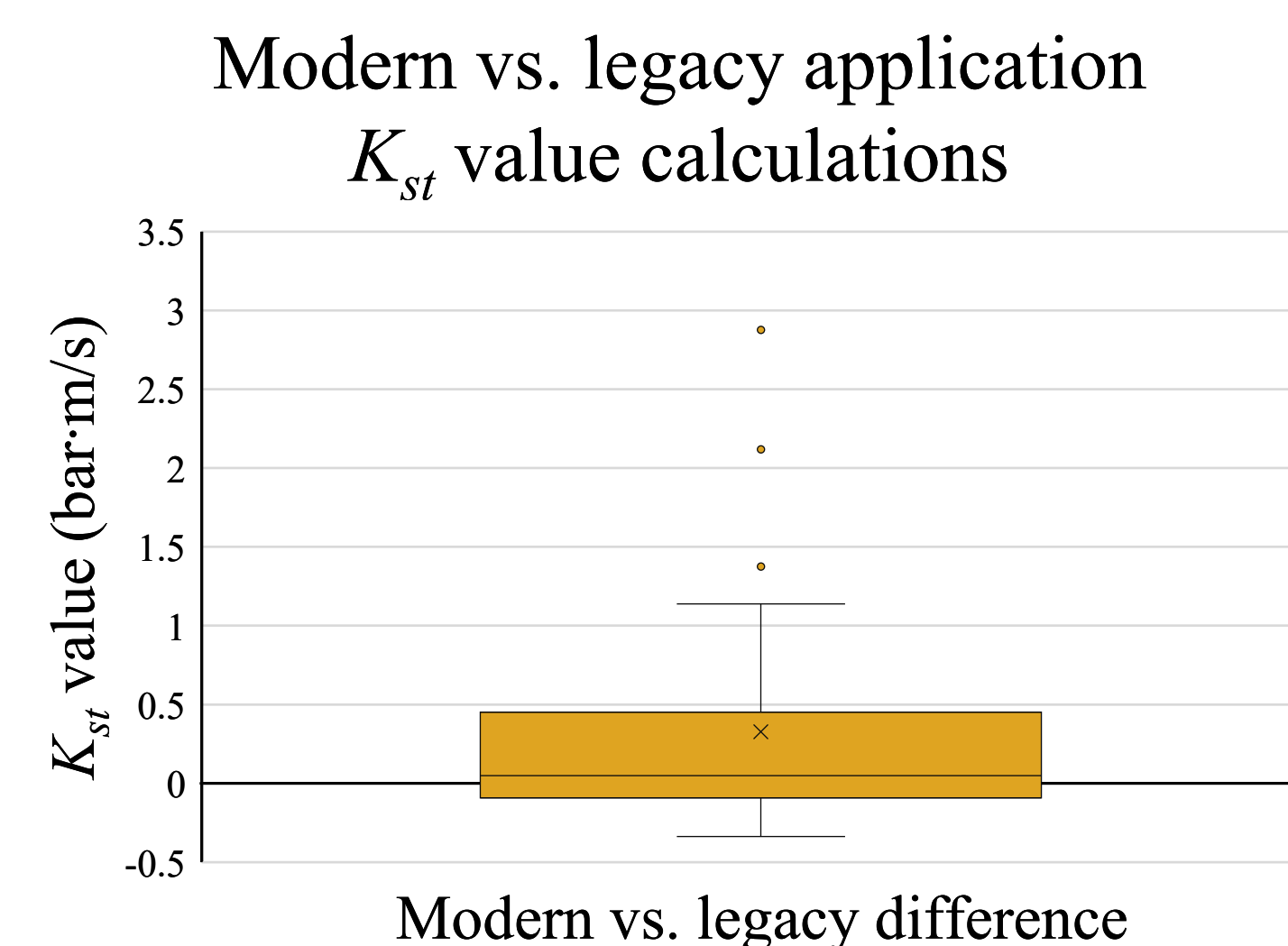
Figure 2 (above): The K_{st} Analyzer reads .h5 files generated by ATC sensors and has raw, smoothed, derivative, and integral graphing, as well as multiplot capabilities.

The K_{st} was calculated using both the legacy and modern application using data imported from pressure–time datasets and recorded into Excel. This approach enabled direct comparison between methods to evaluate systematic differences in K_{st} calculations.

Results

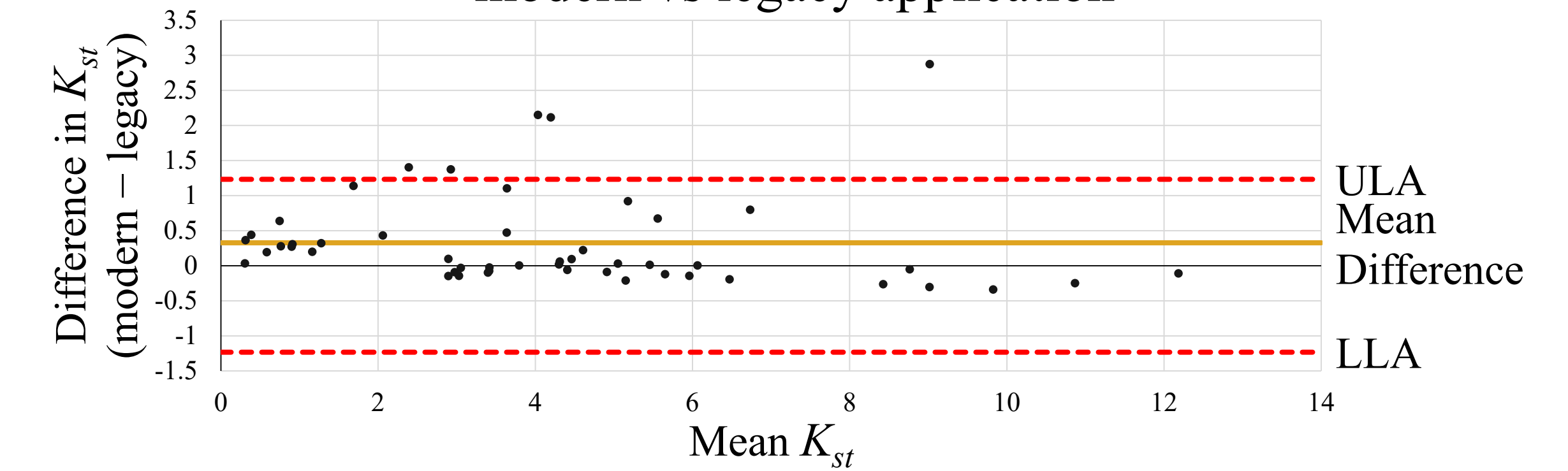
The MFBG CAD model was sent to the ATC engineers and is awaiting assembly in the late spring. A paired-samples t -test was conducted to compare K_{st} obtained from the application and manual method (Graph 1). There was a statistically significant difference between the two methods, $t(49) = 3.41, p = .001$. The mean K_{st} for the application ($M = 4.43, SD = 2.84$) was higher than the manual method ($M = 4.10, SD = 2.91$). The mean difference between methods was 0.33, with a 95% confidence interval from 0.13 to 0.52.

Graph 1 (right): A boxplot shows multiple outliers in the difference between the modern and legacy K_{st} values. The mean also is shown to be higher than the median, showcasing the effect of the outliers.



Results (continued)

Bland–Altman plot for K_{st} calculation from modern vs legacy application



Graph 2 (left): Bland–Altman plot comparing K_{st} values from the modern and legacy applications. A consistent positive bias is observed, with the modern method producing higher values. The 95% limits of agreement (–1.23 to 1.23 bar·m/s) show moderate variability, with most points within this range. No clear relationship between mean K_{st} and difference is observed, indicating consistent bias across measurements.

Conclusion

In evaluating the modernization of the application for improved K_{st} analysis, a consistent upward shift in calculated K_{st} was observed, with the new application producing significantly higher results than the legacy method, indicating systematic bias. The Bland–Altman analysis (Graph 2) confirmed this, likely due to using the maximum derivative rather than manually selected slopes. These results indicate that the modernized application produces significantly higher K_{st} values than the legacy application calculation. The modern method is theoretically more accurate because it aligns with the standard calculation of a K_{st} and removes subjective input. Accuracy, efficiency, and usability improved through automated true K_{st} analysis, rapid processing and export functions and a streamlined cross platform interface. Although the MFBG was not built in time due to government shutdowns and shifting ATC priorities, the CAD model and modernized application provide a strong foundation for future work, enabling standardized K_{st} analysis and reliable evaluation of fireball performance.

References

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