Exhibit F - UTCRS

UTC Project Information	
Project Title	Radiative Heat Transfer Analysis of Railroad Bearings Using a Single Bearing Test Rig for Wayside Thermal Detector Optimization
University	The University of Texas Rio Grande Valley (UTRGV)
Principal Investigator	Stephen Crown, Ph.D., Mechanical Engineering (PI) Constantine Tarawneh, Ph.D., Mechanical Engineering (Co-PI)
PI Contact Information	Mechanical Engineering ENGR 3.234 Dept. (956) 665-2394 Office (956) 665-5015 stephen.crown@utrgv.edu
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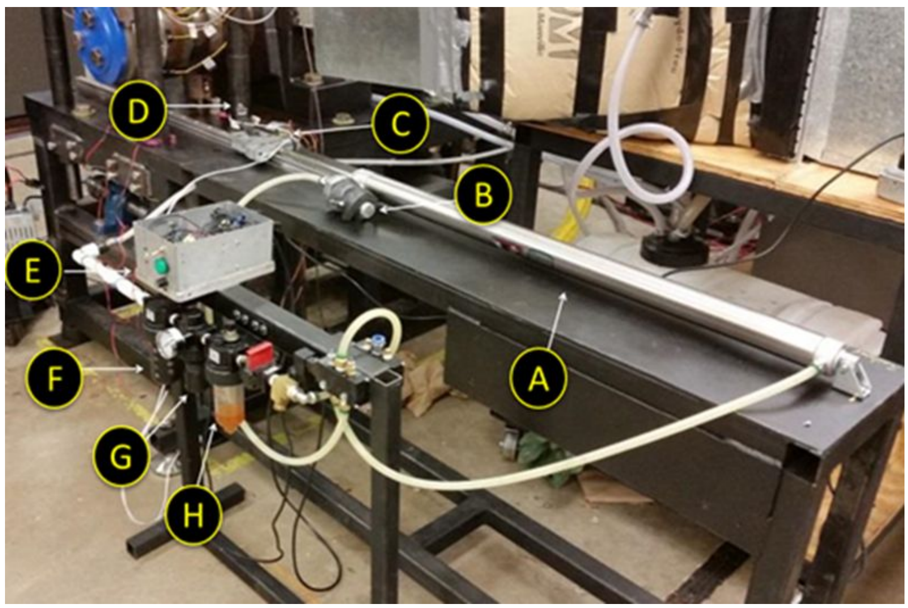
Total Project Cost	$89,134
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	January 2015 – December 2018
Brief Description of Research Project	Wayside hot-box detectors (HBDs) are devices that are currently used to evaluate the health of railcar components including bearings, axles, and brakes by monitoring their temperatures. While HBDs have been instrumental in reducing some train derailments in the past few decades, the number of non-verified bearing removals has increased significantly. In general, HBDs tend to underestimate bearing temperatures in both field service and in laboratory testing, which is not surprising considering the simple calibration method that is used to calibrate these devices. Because of this, different calibrations were compared and analyzed including two-point, three-point, and multi-point calibrations. Analysis of the results also suggests that the scanning location significantly affects the temperature measurement. The work summarized here describes how an optimized calibration

	technique along with proper infrared (IR) sensor alignment can markedly improve the accuracy and precision of wayside HBD temperature measurements in field service.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	An investigation into the efficacy of wayside HBDs that are currently used in rail service was conducted. A laboratory HBD simulator, pictured in Figure 1, was fabricated to mimic the functionality of the wayside HBDs in field service by traversing an infrared (IR) sensor underneath a bearing to take a dynamic temperature measurement. Numerous experiments were performed in the laboratory using healthy and defective bearings at various speed and load conditions. The data was analyzed and then subsequently compared with the data acquired during an on-track field service test.  **Figure 1. Laboratory Hot-Box Detector Simulator. From A through H there is the cylinder [A], the quick exhaust valve [B], the cart [C] with the sensor [D] attached, the control box [E], the filter [F] for the pneumatic system followed by the regulator [G] and the lubricator [H].** Analysis of the results has led to many important conclusions. It was found that field service HBDs are greatly affected by the bearing class due to the fact that the change in bearing dimensions between bearing classes causes the infrared (IR) sensor to scan different regions of the bearing outer ring (cup). In order to verify this observation, laboratory data was acquired at different scanning locations on the bearing. The IR temperature data acquired at the inboard raceway location on the bearing cup is shown in Figure 2. In the laboratory, it was concluded that the scanning location on the

bearing significantly affects the temperature measurement of the laboratory HBD simulator, with the most accurate and precise results coming from the inboard raceway region of the bearing cup. These observations are important because incorrect bearing temperature measurements can lead to unnecessary and costly train stoppages and delays or, in some cases, may result in catastrophic train derailments.

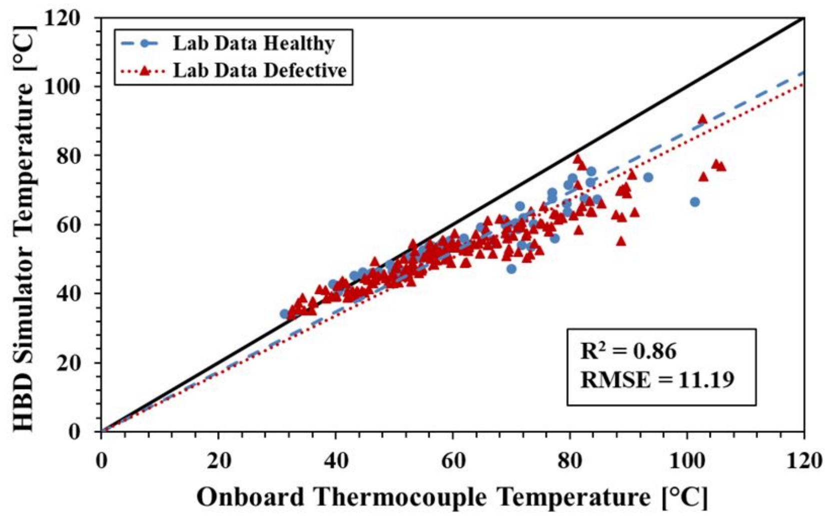


Figure 2. Raw laboratory HBD simulator temperature versus onboard bayonet thermocouple temperature for the bearing inboard (IB) raceway location

Generally, wayside HBDs tend to underestimate the temperatures of bearings in field service operation, which is not surprising given the simple one-point calibration procedure that is used to calibrate these devices. This temperature underprediction can have disastrous consequences, especially if a defective bearing goes undetected by a wayside HBD. This scenario has occurred on numerous occasions in the past two decades in the U.S. and Canada. Hence, an optimized calibration technique along with proper infrared (IR) sensor alignment can markedly improve the accuracy and precision of HBD temperature measurements, which in turn, can reduce: (a) costly delays and train stoppages associated with false warm bearing trending events, and (b) catastrophic bearing failures associated with HBDs underestimating the operating temperatures of defective bearings. This study explored different calibration techniques and applied these techniques to the data that was acquired in the laboratory and from a specially planned service field test. It was found that using more calibration points significantly improved the accuracy of wayside HBD temperature measurements, while having no effect on the precision. The root-mean-square error of the laboratory-acquired data, provided in Figure 3, shows how adding more points to the calibration improves the data by decreasing its error for each scanning location on the bearing. Additionally, calibrated data acquired by the laboratory HBD simulator at the bearing inboard raceway scanning location is provided in Figure 4. Comparing Figure 2 to Figure 4, one can notice the marked improvement in the accuracy of the data after applying the all-data calibration technique.

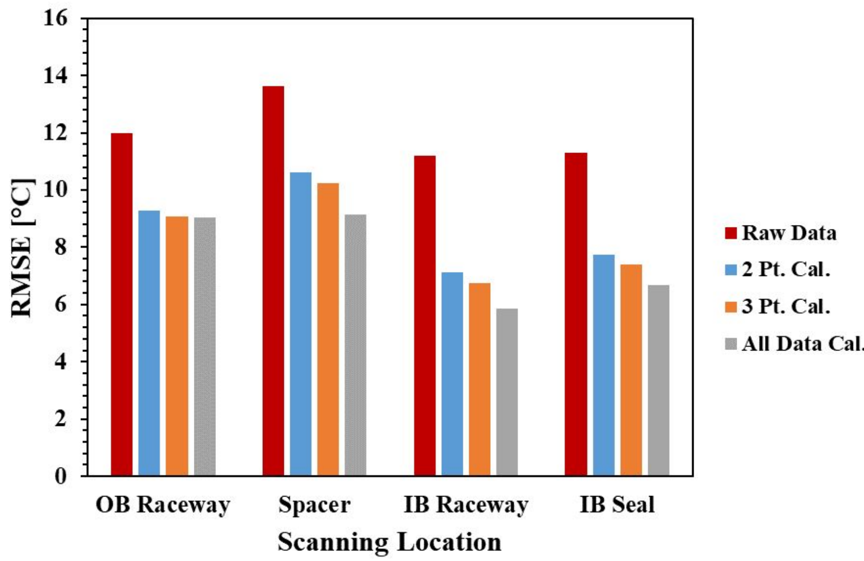


Figure 3. Laboratory data root-mean-squared-error (RMSE) comparison for various calibrations at each scanning location

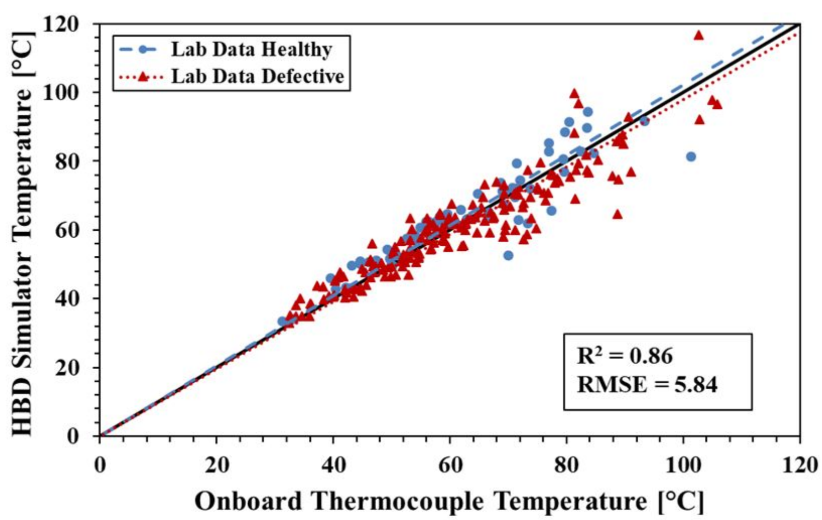


Figure 4. Calibrated laboratory HBD simulator temperature versus onboard bayonet thermocouple temperature for the bearing inboard (IB) raceway location

Similar results were achieved when applying the all-data calibration technique to the field-acquired data recorded using in-service wayside HBDs, as demonstrated by Figure 5 and Figure 6.

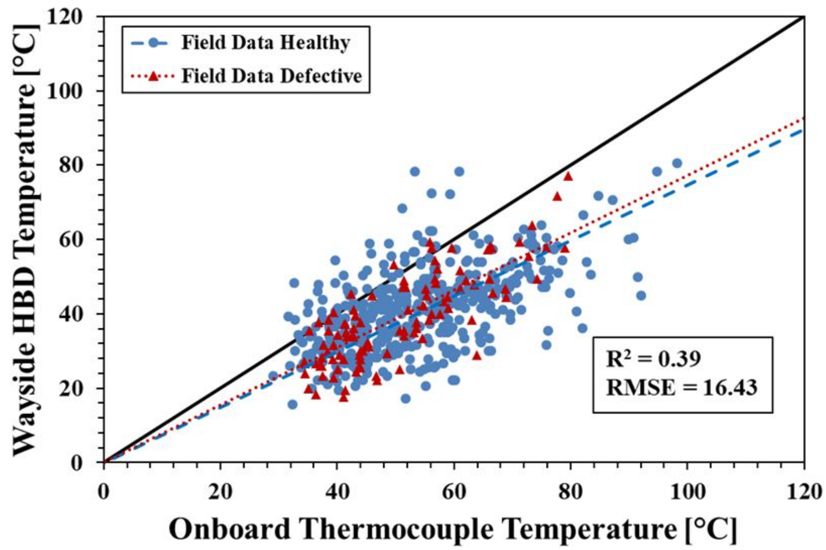


Figure 5. Raw field-test wayside HBD temperature versus onboard thermocouple temperature

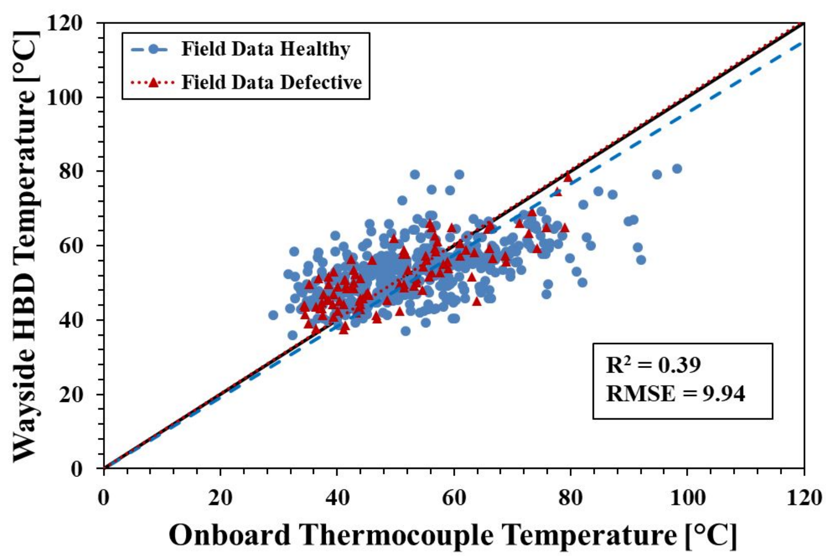


Figure 6. Calibrated field-test wayside HBD temperature versus onboard thermocouple temperature

Detailed analysis of the data and the calibration techniques used to improve the accuracy of the IR recorded bearing operating

	temperatures can be found in the master’s thesis that resulted from the work performed on this project.
Impacts/Benefits of Implementation (actual, not anticipated)	This study will serve to assist the railroads in the evaluation of the efficacy of current bearing condition monitoring systems, which will further the advancement of safety technologies in the railway industry. The findings of this study can save the rail industry expenses incurred in property damage caused by train derailments and hundreds of labor-hours lost from false bearing set-outs. The laboratory HBD simulator that was developed as part of this project is a state-of-the-art, unique technology that allows for the fast and efficient evaluation of IR-based HBD systems in a laboratory setting. The research performed for this UTC project has resulted in a master’s thesis, one international journal publication and presentation, and two international conference publications and presentations. The list of publications for this project include the following: 1. Aranda, J., “Radiative Heat Transfer Analysis of Railroad Bearings for Wayside Thermal Detector Optimization,” Master's Thesis, Department of Mechanical Engineering, The University of Texas Rio Grande Valley, December 2018. 2. Tarawneh, C., Aranda, J., Hernandez, V., and Mealer, A., “An Investigation into Wayside Hot-Box Detector Efficacy and Optimization,” *Int. J. of Railway Technology*, under review, submitted December 2018. 3. Tarawneh, C., Aranda, J., Hernandez, V., and Ramirez, C., “An Analysis of the Efficacy of Wayside Hot-Box Detector Data,” *Proceedings of the 2018 ASME Joint Rail Conference*, Pittsburgh, PA, April 18-20, 2018. 4. Mealer, A., Tarawneh, C., and Crown, S. W., “Radiative Heat Transfer Analysis of Railroad Bearings for Wayside Hot-Box Detector Optimization,” *Proceedings of the 2017 ASME Joint Rail Conference*, Philadelphia, PA, April 4-7, 2017.
Web Links • Report • Project Website	http://www.utrgv.edu/railwaysafety/research/mechanical/2015/ radiative-heat-transfer-analysis-of-railroad-bearings/index.htm