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Aerodynamic Effects of High-Speed Trains

SUMMARY

With the onset of high-speed train operations in the United States, a study was undertaken to determine the possible aerodynamic effects of these trains have on their surroundings. The aerodynamic interaction between a high-speed train passing other trains, and its effects on the structural integrity of window mounts and glazing as well as the stability of large lightweight empty container cars operating on adjacent tracks (Figure 1) were analyzed. Although car-body roll of container car was not significant, the analysis indicates that the potential for derailment was greatest for cars with empty containers, while wheel lift was eliminated and the lateral to vertical wheel/rail forces (L/V) were much lower when all containers were fully loaded. Another area of investigation focused on the effects of aerodynamic pressure and airflow generated from high-speed trains to people standing on the passing station platform (Figure 2). Computational fluid dynamics analysis, rail dynamics simulation models, and field measurements using pitot tubes and aerodynamic dummies developed by the French National Railways (SNCF) were used to study these effects. Preliminary results show the aerodynamic effect of an Acela Express at 150 mph is less than that of a conventional train at 125 mph.

Figure 1. Test setup for high-speed train operating adjacent to container cars.

Figure 2. High-speed train passing through a station at 150 mph.

BACKGROUND

A state of the art review of the subject of aerodynamic issues created by high-speed trains was conducted and is presented in [1]. This review revealed potential areas of concerns that required further studies with an emphasis on high-speed trains passing people standing on platforms as well as large empty container cars. Five studies within these two areas were conducted to address these issues.

- The first was a computational fluid dynamics (CFD) analysis result for aerodynamic forces created by high-speed passing high and low level platforms.
- The second was field measurements using pitot tubes to determine the wind speeds created by high-speed trains and comparing the results with CFD analysis.
- The third study used CFD analysis and rail dynamic simulation programs to evaluate the effects of high-speed trains on lightweight freight equipment operating on adjacent tracks. Different aerodynamic load scenarios and train configurations were evaluated to determine potential derailment conditions.
- The forth study consisted of field measurements using pressure transducers to determine the aerodynamic forces on a well car with empty double stacked containers as a high-speed train passed by.
- The last study consisted of field measurements of aerodynamic forces created by different high-speed train configurations passing a platform. Data was collected using instrumented devices developed by the French National Railroad (SNCF).

TESTING PROGRAMS

The first area of study examined the aerodynamic effects high-speed trains have when they pass platforms [2]. Using CFD analysis modeling, results were obtained for the Acela Express trainset, consisting of six coaches and two power cars at 150 mph, and an Amfleet train, consisting of an AEM-7 electric locomotive with six coaches at 125 mph. A comparison of the train configuration shows that the Amfleet train induces a higher airflow than the Acela, except at the wake, where the Acela trainset was generally higher.

Field measurements were conducted to obtain data for comparison with results computed from the mathematical model. The first series of field tests used pitot-static tube devices to measure airflow parallel to the track and in the direction of the passing train as shown in Figure 3. The second series of field tests used cylindrical aerodynamic dummies designed and operated by the SNCF shown as in Figure 4. These dummies were designed and instrumented to measure the resultant force due to the imbalance in the aerodynamic pressures acting on it.

Figure 3. Pitot-static tubes mounted on stand for measuring airspeed.

Figure 4. Circular cylindrical test dummy designed to measure resultant force applied to the cylinder.

The results from both field tests compare well with the mathematics models indicating the slender nose high-speed train like Acela Express creates less aerodynamic forces than the bluff nose train like the AEM-7 locomotive.

A second area of study pertained to aerodynamic projects related to the likelihood of large surface, lightweight objects, such as empty containers, being dislodged due to the aerodynamic loads generated by passing high-speed trains. CFD analysis and a rail dynamics simulation program were conducted to determine the resultant motion and risk of derailment of the passing trains. Twelve different test scenarios were run varying the high-speed and freight trains speed, direction as well as the ambient wind speed and direction.

The results indicated that the amplitude of the loads depends mostly on the speed of the high-speed train and the presence of a headwind. It was determine that the maximum aerodynamic forces on the container trains occur when it moves in the opposite direction to the high-speed train. The maximum impulse is generated when the two trains are moving in the same direction at intermediate speeds thereby producing long pulse duration's that tend to maximize response and the risk of derailment.

To verify the CFD analysis and rail dynamics simulation models, a field test was conducted to gather pressure-time histories of a stationary freight car as a high-speed train passes. Ten pressure transducers were placed on the container facing the passing train and two were placed on the opposite side. Strain gages and laser beams were used to determine train positions. A string potentiometer was connected to the container car to measure the amount of tilt produced. Weather data was also collected to establish base line criteria.

The results of the pressure data for all passes were within expectations of the mathematical predicted results. The peak roll response of the container car is shown in Table 1. The roll angles are not significant, where the largest response occurred when the high-speed train passed at 110 mph.

Table 1. Maximum car-body roll response of container car from train passing by on adjacent track.

Speed of Passing High-Speed Train	Maximum Roll Angle of Container Car, Zero-to-Peak (deg)	Maximum Lateral Displacement at top of Container, Zero-to-Peak (inch)
60 mph	0.055	0.207
80 mph	0.117	0.444
100 mph	0.218	0.829
110 mph	0.312 (highest response)	1.184
120 mph	0.281	1.065
130 mph	0.281	1.065

CONCLUSIONS

Preliminary results from the station platform study indicate that the aerodynamic effects of an Acela Express trainset traveling at 150 mph are less than that of an Amfleet train traveling at 125 mph. Also, the airflow from a low level platform is stronger than from a high level platform.

The results from the double stack container car study indicate the potential for derailment was greatest for cars with empty containers, while wheel lift was eliminated and the lateral to vertical wheel/rail forces (L/V) were much lower when all containers were fully loaded. Car-body roll for the container car was not significant.

FOR FURTHER RESEARCH

Measured data of airspeed and forces on cylindrical dummies are currently being processed and analyzed. A report is being prepared that will include research results since project inception and latest test results.

ACKNOWLEDGMENTS

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REFERENCES

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DEFINITIONS

Acela Express: high-speed electric passenger trainset consisting of six coaches with a power car on each end operating on the Northeast Corridor between Boston, Massachusetts and Washington DC.

Amfleet: conventional passenger train with Amfleet coaches that are pulled by locomotives such as the AEM-7 electric locomotive.

KEYWORDS

High-speed trains, aerodynamics, platform safety, computational fluid dynamics