Research on Railroad Petroleum Conservation

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Although U.S. railroads consume less than 3 percent annually of the nation's petroleum, apprehension about the continued availability and increasing price of diesel fuel has fostered a variety of research projects. The results offer significant new knowledge and analytical techniques on potential ways to conserve this valuable asset. This paper describes the research efforts and some of the major results, which include (a) development and application of several versions of train-performance simulators, (b) wind-tunnel and full-scale investigations of the effect of aerodynamic drag, (c) preliminary insight into the potential of alternative fuels for diesel locomotives, (d) feasibility studies of the concept of stored energy in both yard and line-haul applications, (e) prototype development and initial testing of a critically needed measuring device called the Locomotive-Data-Acquisition Package, and (f) thorough audit of petroleum consumption on a small class I railroad. It is not possible to quantify the amount of fuel saved as a result of these efforts. The dissemination of findings, however, has stimulated the design and production of new equipment, caused some changes in railroad operating practices, and focused attention on areas for further research.

In the two decades since they became completely dieselized, the railroads of the United States have increased their service to a level at which they now consume about 4 billion gal of fuel annually. This is less than 1 percent of all energy consumed and only about 3 percent of total energy (all sources) used by transportation. With average 1980 prices approaching $1/gal, however, the industry must further reduce its consumption even though it is a small portion of that used nationally. Further, there is always the threat of reduced availability as a result of changing conditions abroad.

An important mission of the Federal Railroad Administration (FRA) is to assure that railroads remain in the private sector. One way to achieve that is to assist railroads in reducing their costs through the conduct of research and development projects. These projects are categorized in different ways for purposes of budgeting, reporting, and managing. This paper focuses on petroleum conservation research. In contrast, petroleum avoidance (as might be achieved by electrification or the introduction of more-advanced propulsion systems) is explicitly not included.

LOCOMOTIVE-RELATED PROJECTS

Multiple-Unit Locomotive Throttle Control

The movement of most trains requires a locomotive consist of more than one unit to maintain schedule and traverse ruling grades. When the available power and tractive effort exceed the demand, there is no need to have all units operating at high throttle settings. Accordingly, several commercial devices, generically called fuel-savers, were offered to the industry in the early and mid-1970s. Their general acceptance by locomotive manufacturers and railroads was slow.

In 1977, FRA undertook a modest evaluation project in an attempt to verify the validity of some of the claimed savings. With the cooperation of two major western railroads, the semiautomatic version of one type of fuel saver was installed and tested on a series of trains. Even with the many variances associated with terrain, size of train, skill of the engineer, weather conditions, etc., for this particular set of operating conditions, the average fuel savings was of the order of 10 percent.

In recent years additional commercial devices have entered the market and achieved reasonable penetration. Some devices are now fully automatic. The following describes the conduct of the project; for more detail, see the FRA report by Jacobs (1).

The test device consists of a control box mounted on the control stand of the lead unit of the consist and a fuel-saver setup switch on the isolation panel of each trailing unit. Electrical wiring is accomplished through two available pins in the jump cable between individual locomotives; such a setup is not radio-frequency-controlled.

The test series involved two distinctly different train configurations that operated in two quite different rail environments. In the first test series, four turbocharged SD 40-2 locomotives pulled a slow, 14 000-ton, 110-car unit coal train across predominantly level terrain for 682 miles at an average speed of 25 mph. This was in marked contrast to the second test, a high-priority trailer-on-flatcar (TOFC) train. Powered by two EMD DD 40s and one SD 40-2 for a total of 16 200 hp, this 2500-ton, 30-car train reached an average speed of 50 mph in spite of the 1519 miles of extremely variable and somewhat mountainous terrain. The advantages of testing dedicated unit trains that operate between points A and B were the predictable operating speeds and the relatively constant trailing gross tons and number of cars per train.

For both test series, one round trip was conducted during which the fuel-saver system was off (control test) and one round trip was conducted during which the fuel saver system was on. The accumulated mileage per round trip was 1364 miles for the unit coal train and 3038 miles for the unit TOFC train. The unit coal train actually performed two tests. For the outbound leg, the coal train was loaded. After dumping the coal at the end point, the train returned on the inbound leg empty. All testing proceeded within the normal operational framework of each railroad.

Scale weighing both the coal and the cars ensured less than 3 percent variation in trailing loads per test for the loaded unit coal train. Such information was not readily available for TOFC trains; instead the gross tons per car were determined by adding the tare weight to the estimated trailer-plus-lading weight supplied by the shipper.

To aid the subsequent analysis, the above data were supplemented by using track profiles, track diagrams, and mileage tables. All speeds, temperatures, throttle positions, and alternator currents were recorded for the lead locomotive only. In addition, a set numeric order for manually recording all other pertinent locomotive data was established and adhered to throughout the tests.

The locomotives assigned to both test consists had all been screened for potential problems in regularly scheduled 15- or 30-day inspections just prior to testing. Their performance characteristics and fuel efficiencies, therefore, were considered to be typical of the average locomotive operating under similar conditions.

To record diesel fuel consumption to the nearest gallon, two calibrated volumetric flow meters were installed in each of the four locomotives of the unit coal train and in each of the five power plants of the three-locomotive unit TOFC train. The difference in meter readings between the supply line and the return line to the fuel tank indicated the fuel consumed per locomotive. The meter readings were recorded manually at the end of each test zone as well as for any delay encountered. Because of the number of crew changes per test and the importance of the locomotive engineer in evaluating the performance of the fuel-saver system, a test zone was defined as that distance traveled before a crew change occurred.

Effective use and operation of the throttle-control device was highly dependent on the skill of the locomotive engineer. Skill in this instance was indicated by the engineer's ability to match the use of the fuel saver to the track profile and the power requirements. For each fuel-saver test the locomotive operating engineer was instructed by on-board test personnel to keep the locomotive consist at the seventh and eighth throttle positions as much of the time as possible. The fuel-saver switches were employed to reduce power when necessary without sacrificing track speeds or operating schedules. Because of the numerous crew changes on both the unit coal train and the unit TOFC train, the time and number of locomotives in the fuel-save mode varied considerably.

For the unit coal train, 79 percent of the route miles had less than 0.5 percent grade, and the overall reduction in fuel consumption was 9.8 percent. This was approximately zero savings for the loaded train and more than 20 percent for the unloaded return. In contrast, the unit TOFC train, which had an average speed of 50 mph, achieved a reduction of the order of 12 percent.

The above results were not conclusive in the sense that the measuring equipment worked perfectly, the environment was typical, or that mixed trains would respond in a similar manner. But the numbers produced by the evaluation did stimulate much discussion and further testing. In the near future, new locomotives will be offered to the railroads that have a fuel saver as an optional item.

Locomotive-Data-Acquisition Package

Any project for fuel-consumption improvements--whether it involves the use of alternative fuels, diesel heat recovery, energy storage, traction control, or improved operating procedures or equipment--must be based on statistically valid samples of engineering data gathered under a wide variety of operating conditions; the problem that arises is the lack of adequate technical data on which to base decisions. The importance of statistically valid data under actual railroad freight operating conditions cannot be overstated.

In previous research efforts, extensive examinations of the literature failed to produce actual published data on locomotive equipment operation; questions that appear almost trivial often remain unanswered. For example, at different times attempts have been made to determine (a) locomotive fuel economy as a function of train handling and ratios of horsepower per ton, (b) traction motor efficiencies, (c) locomotive voltage transients (their causes, effects, and magnitudes), (d) slip/slide circuitry performance and efficiencies, and (e) aerodynamic forces on containers, boxcars, and trailers. Further, it is not clear how to write a good performance specification for equipment carried by a locomotive--the shock levels, the vibration levels, the electromagnetic interference environment, etc., are unknown. The lack of this information has definitely been an impediment to research efforts. In a larger sense, it has also prevented new companies from successfully entering the railroad marketplace. Private companies could conceivably supply equipment for research investigations, but unless the environment is described accurately, suppliers are reluctant to risk investment in developing such equipment.

FRA is sponsoring a project at the Lawrence Berkeley Laboratory (University of California, Berkeley) to develop a portable locomotive-data-acquisition system in an attempt to obtain and publish some of the information noted above. The system includes not only the locomotive-data recorder but also an ensemble of transducers and some analysis software. The system is known as the Locomotive-Data-Acquisition Package (LDAP) (2). The data-recorder portion of the system is minicomputer-based; it is designed to be installed in the long-end hood of a freight locomotive. The immediate objective for the LDAP project is to prove the validity of the concept and to establish the reliability and credibility of the device.

Field testing was initiated in the summer of 1979 at the Transportation Test Center in Pueblo, Colorado. After minor revisions, the equipment was installed on a small New England railroad. After further modification, the equipment was installed on a major western railroad in the summer of 1980. At the time of this writing, the data analysis was not complete, but much had been learned about the operating environment.

Alternative Fuels

In 1978, under FRA and U.S. Department of Energy (DOE) sponsorship, investigation of alternative fuels in medium-speed (800-1200 rpm) diesel engines began. Two categories of fuels are being investigated--off-specification diesel fuels and nondiesel fuels. These fuels are defined as follows.

Off-specification diesel fuels are currently defined by setting quantitative values or limits on properties such as cetane number, viscosity, boiling range, ash and sulfur content, and so forth. Engine manufacturers recommend a certain minimum fuel specification and define performance of their engines in terms of this specification. Crude petroleum must then be refined in the manner required to produce such a fuel. If one or more fuel specifications could be relaxed and still permit acceptable engine performance, the number of steps and energy in the refining process could be reduced and less-expensive and/or higher-availability liquid hydrocarbon products could be produced for use as finished engine fuels.

Nondiesel fuels include such fuels as alcohol and gasoline. These fuels obviously differ greatly from specification diesel fuel with respect to cetane number, viscosity, boiling range, and other characteristics. Nondiesel liquid fuels derived from coal are also placed in this category for purposes of this project.

The objectives of the current test program are as follows:

1. Through experiments with a two-cylinder, two-stroke-cycle, medium-speed diesel engine to define the degree to which pertinent properties of diesel fuels can be varied from specification values and still allow acceptable fuel economy, combustion characteristics, exhaust-emission levels, and piston-ring wear;
2. To perform a similar series of engine experiments by using alcohol (methanol), gasoline, and a simulated coal-derived liquid as primary engine fuel (ignition of the primary fuel to be obtained by pilot injection of diesel fuel); and
3. To prepare a comprehensive program plan for the future investigation of alternative fuels for medium-speed diesel engines to use results of the current project by other organizations and engine

manufacturers [as part of the planning, the Association of American Railroads (AAR), the locomotive manufacturers, and other interested railroad industry groups are actively participating in the coordination of the program plan].

The test engine used in the current program, which is being conducted at Southwest Research Institute (SwRI), is a two-cylinder, two-stroke-cycle EMD model 567C that features bore and stroke of 9.5 and 10.0 in, compression ratio of 16:1, and needle-valve-type unit injectors. The engine is instrumented to obtain data on engine speed and torque, continuous pressure in one cylinder, injection timing, fuel-consumption rate, and pertinent temperatures and pressures. Opacity of exhaust smoke is measured by the Borsch method. The engine is set up to run at the nine speed and load conditions commonly used in line-haul locomotive service.

The so-called regulated diesel emissions (unburned hydrocarbons, oxides of nitrogen, and carbon monoxide) are measured by using conventional instrumentation. The particulate content of the exhaust is measured in a stainless-steel dilution tunnel.

Rate of piston-ring wear is measured by the radioactive-tracer technique. This method employs a radioactive piston ring and continuous measurement of the amount of radioactive wear particles in the lubricating oil. A stabilized rate of wear can be measured for a given combination of speed, load, and fuel in one 8-h shift.

A standard commercial no. 2 diesel fuel that meets all the requirements of ASTM D975 was selected as the base-line fuel for this program. Engine experiments have been conducted by using the following off-specification diesel fuels:

1. Low-cetane-number fuel series: Cetane number was systematically reduced from the base-line value of 55 by blending progressively greater amounts of secondary fuel components with the base fuel (the lowest cetane number thus obtained was 17);

2. Nonstandard-distillation-range fuel series: These fuels were obtained by blending the base fuel with either lube oil stock or unleaded gasoline and by blending lube stock with gasoline; varying the amount of each constituent in these blending schemes produced so-called dumbbell fuels (which have a preponderance of light and heavy ends) and extended-boiling-range fuels (which have a preponderance of either light or heavy ends); (it is important to note that all these fuels could be obtained in practice by blending common components, which would produce a greater quantity of an off-specification fuel);

3. High-viscosity fuel series: A heavy fuel that had a viscosity of 145 cSt at 40°C was gradually heated to reduce the viscosity (this approach allowed all other fuel properties to remain unchanged while viscosity was altered);

4. Water-in-fuel emulsion: Water (10 percent by volume) was emulsified into the heavy diesel fuel, and a stable emulsion was obtained by adding a small amount of surfactant; the amount of water in the emulsion was later increased to 20 percent by volume; and

5. High-sulfur fuel series: Sulfur-containing additives were included with the base fuel to increase the sulfur content from the normal value of 0.2 percent by weight to about 1.0 and 1.5 percent (since sulfur content has no significant effect on engine performance, only emission and ring-wear measurements were conducted by using these fuels).

Results of the initial test series will be available in a joint DOE-FRA report during 1981.

The next phase of the alternative-fuel test program will involve the selection of nondiesel gaseous fuels (e.g., hydrogen, propane, and dissociated alcohol) for two-cylinder engine experiments; the development of criteria for fuel screening (cost, safety, handling, engine use) based on previous results; and multicylinder engine experiments that use the off-specification and nondiesel liquid fuels with both General Motors (GM) and General Electric full-sized locomotive diesel engines. The actual candidate fuels identified in this screening process for further testing and evaluation will be compared closely with the recommendations of the DOE study performed by Exxon Research and Engineering Company on alternative energy courses for nonhighway transportation (3).

Because of their outstanding capabilities for this type of research, SwRI also has been sponsored by the AAR to address the question of claims for fuel additives. As a result, there now exists a three-step evaluation process in which each step provides more tests at a higher cost that can be used by the developers of commercial products or by their potential customers. Such tests are independent of FRA; the proprietary results are given only to the firm that funds the evaluation.

Flywheel Energy Storage Switcher

A study was performed to quantify the benefits to be derived from recovery of braking energy from a switching locomotive as it decelerates a cut of freight cars during the switching operation (4). To minimize hardware, the energy storage unit chosen was the one developed for the U.S. Department of Transportation Advanced Concept Train (ACT-1) vehicles, the flywheel energy storage switcher (FESS).

Since this system required the use of separately excited traction motors, a major task of the project was to test a separately excited version of the GM Electromotive Division's D77 traction motor. The benefits of this system were clearly dependent on the operating duty cycle of the switching locomotive; therefore, the study examined in detail the operation of three flat yards to develop a realistic operating scenario.

To accurately predict the performance of the FESS system, a computer model was produced that, starting with the internal parameters of the diesel locomotive, is able to predict fuel consumption of the locomotive with and without a flywheel system. The correlation of this model was shown by comparison with the measured yard data.

The study concluded that a boxcar was necessary to carry the energy storage unit because there was no room in the locomotive. The boxcar and the increased auxiliary load resulted in approximately the same total energy consumption, with or without the FESS system, as would be used for a typical flat-yard operation, in spite of the energy recovered and reused. Brake-maintenance savings, although significant, were not sufficient to give an attractive return on investment. As a result, no further research has been done on the subject.

Wayside Energy Storage System

A study was performed to quantify the benefits to be derived by recovery of braking energy from freight trains that are descending long grades (5). This energy, now wasted by dynamic or friction braking on the diesel-electric and electric locomotives, represents a valuable resource that could be conserved. As an example, in the hour it takes a large freight consist to descend Cajon Pass near San Bernardino, California, enough electrical energy can be generated to supply a residential community of 30 000 for 1 h. Storing this energy for use by an ascending consist would substantially reduce energy costs for the railroad. For the Cajon Pass example, about $500 (1977 fuel costs) in savings for diesel fuel would be realized from the recuperative braking of each large consist.

The energy-storage concept could be supplanted by the availability of a receptive electric utility tied to the electric lines used for regenerated electric power on the grades; however, this mode of operation is possible with only a few utilities that have policies permitting them to accept power from intermittent sources. Also, if the utility accepts such power, it is bought back at a price substantially below the cost of newly generated and distributed power from the utility, often at zero credit to the customer.

Still another approach to recovery of braking power would be the scheduling of train operations so that a receptive (ascending) train was available when a train was descending the grade. Such an energy interchange would require an unrealistically precise scheduling of train operations. Also, in the real world of freight railroads, other factors that appear to make the direct interchange of energy between trains impractical include the following:

1. Many grades are single track and require consecutive train operations;
2. Most railroads have a greater flow of freight in one direction than in the return direction; and
3. The time required to ascend a grade is usually different for different trains.

Consequently, it is necessary to provide an energy storage system at grades that possess the proper combination of traffic density and length. These energy storage systems would be installed at the wayside rather than on board the locomotives. This is because the required level of energy storage (up to 3 MW•h/locomotive) makes the size and weight prohibitive for vehicle installation.

A number of wayside energy storage system (WESS) configurations were considered before the conclusion was reached that the optimum system would be one in which the interface between the locomotive and the storage device is a high-voltage alternating-current catenary and the storage device is a flywheel. The optimum system requires locomotives that have a fully regenerative capability. For an electrified railroad, this is relatively easy to achieve with modern electric locomotives. For the more-common diesel-electric railroad, major modifications to the locomotives are necessary. Consideration of this requirement led to the concept of dual-mode locomotives (DMLs), in which a standard diesel-electric locomotive (such as the SD 40-2) is equipped with pantograph, transformer, thyristor converter, and choke to enable it to operate as either a diesel-electric or an electric locomotive.

The optimum flywheel design was determined to be one that has a steel rotor that weighs 604 tons and has a diameter of 15.3 ft and a length of 19 ft. The flywheel, rotating at speeds that range from 1017 to 2037 rpm, would be installed in a pit below ground level on the wayside adjacent to the grade.

The study concluded that, based on the nine railroads surveyed, up to 80 locations existed at which WESS systems could be economically deployed. The spread of railroad electrification would increase the number of potential sites.

DMLs

The DML concept, developed during the above study, is a locomotive that can operate either from an on-board diesel engine or from a high-voltage catenary via a roof-mounted pantograph. The significance of the DML is that it is able to operate from a high-voltage (25- or 50-kV) catenary; previous concepts for a DML could operate in the electric mode only from a low-voltage (600-V nominal) power source not compatible with main-line railroad electrification. Currently, FRA and DOE are undertaking joint sponsorship of the system engineering of the DML.

The availability of a DML compatible with main-line railroad electrification has a significant impact on both the economics and method of deployment of electrification. One of the major benefits of railroad electrification is the reduction in locomotive fleet size that results from improved availability of the electric locomotive fleet and the increased power available at the locomotive wheels. Furthermore, there is today a significant economic advantage to the railroads in using catenary-derived energy rather than diesel-fuel-derived energy. The DML makes it possible to take advantage of the majority of these benefits for a fraction of the cost of conventional electrification by positioning catenary only at those sections that have high energy consumption, when the performance of the train is limited by the power output of the diesel engine. When operation is from the catenary, the power of the locomotive is no longer limited by the diesel engine but now is limited by the power rating of the traction motors.

On a typical six-axle locomotive, the power capability of the traction motor is 50 percent higher than that of the diesel engine. Therefore, the DML is able to operate at significantly higher power levels in the electric mode than a conventional diesel locomotive can in the diesel mode.

Having initially electrified the sections that consume high power or energy, described above, a railroad that employed the DMLs could achieve a positive cash flow on the investment within, typically, three years (compared with 6-10 years for conventional electrification) and the initial investment would be reduced to 25 percent of that associated with conventional electrification. The bulk of the annual savings is due to the significant reduction of diesel-fuel consumption. Furthermore, the regenerative nature of the DML allows additional savings in electrical-energy consumption and also reduces the peaks of power demand. This application of the DML overcomes two of the major obstacles to railroad electrification, namely, relatively low return on investment and initial investment beyond the reach of most railroads. The resulting positive cash flow can later be reinvested to extend electrification on the chosen route until the whole route is electrified.

The results of the initial system's engineering work will be published early in 1981. With the renewed interest in electrification, it is anticipated that some modest hardware development will be undertaken.

OPERATIONS AND EQUIPMENT-RELATED PROJECTS

Train-Performance Simulation

In 1974, FRA initiated analytical efforts in the area of fuel use in branch-line operations. At the time, this was an assessment of the environmental impact of rail-line abandonment under the assumption that freight would be moved by truck. This work indicated that the typical fuel-efficiency advantage of rail over highway declines sharply for light loads and low train speeds and vanishes at levels common to branch-line operations. The study was then expanded to provide a sensitivity analysis for general freight and passenger service (6). This work was followed by actual revenue-service measurements made on an 87-mile Missouri-Pacific Railroad branch line; these confirmed the basic findings and in addition brought out the importance of fuel use while the engine is idling.

In 1975, both the analytical and the measurement activities were expanded substantially. Development of a comprehensive capability for computer train-performance simulation (TPS) began with purchase of the Missouri-Pacific TPS, which has been modified and expanded greatly since then. It is now fully documented and suitable for a wide variety of freight and passenger-service applications. In addition, a large library of track data has been accumulated. At the same time, a major program of fuel-use measurements was undertaken in order to validate the TPS and to provide a firmly based set of actual values for rail freight-service fuel consumption. Tests were conducted during more than 50 000 miles of line-haul operations, including TOFC manifest freight and unit coal trains, under a wide variety of circumstances (7,8).

Under FRA sponsorship, the Transportation Systems Center also conducted a small but comprehensive review of various strategies for improvement of fuel efficiency in railroad operations (9). This effort covered many aspects of railroading, including locomotive design features, ratios of power to weight and operating speeds, and fuel storage and spillage.

Energy Audit and Evaluation

With the cooperation of a New England railroad, FRA recently initiated a project to audit the complete flow of energy for both transportation and nontransportation use. Results for a typical winter month indicated consumption to be as follows: train operations, 78 percent; facilities, 17 percent; and equipment and vehicles, 5 percent. Of the total distribution, electricity and propane accounted for 4 and 1 percent, respectively. The train-operations value is further broken down into freight (50 percent) and passenger (28 percent). Freight is made up of 39 percent through operations and 10 percent local operations. In the near future, a complete analysis of an entire year will be published.

In parallel with the audit, the project team developed a prioritized list of conservation options to consider for further evaluation. The final list is as follows:

1. Better matching of locomotive power to train tonnage by using train-makeup guidelines;
2. Modified speed profiles, e.g., fewer stops and speed changes;
3. More-efficient throttle settings;
4. Reduced idling time and revolutions per minute for engines;
5. Fuel-saver devices;
6. Drifting rather than power braking;
7. Use of mates for ruling grades;
8. Use of engineer flight plans for minimizing fuel consumption;
9. Reduced fuel spillage (improved fillers and catch pans);
10. Fewer empty car miles;
11. Lubrication-oil recycling;
12. Improved locomotive maintenance;
13. Improved fuel quality; and
14. Fuel preheaters.

By using the TPS discussed above, several base-line routes were developed for through freight trains, which consume 40 percent of the fuel. Fuel meters and other instrumentation were installed on the locomotives that operate over those routes. Data-collection forms were created and observation teams designated. Actual runs commenced in late summer; at the time of this writing, the comparison of results with the base-line predictions was not available.

Train Resistance

An examination of the train-resistance phenomenon (with particular reference to freight trains) was initiated under FRA sponsorship in 1977. During this work, a different methodology for computing the resistance of a given consist was developed that involved calculating the resistance of each car and summing the individual resistances rather than using a single formula for the entire train. This approach enables one to compute the resistance of a given arrangement of cars, which will be different from another arrangement because of the different aerodynamic drag. A computer program was developed that uses inputs describing the types of cars, their weights, and their order in the consist to compute the total train resistance (10).

The program was used further to explore the significance of certain design improvements or equipment modifications on fuel consumption when the train is operated over level tangent track. It was found that under such circumstances the arrangement of the consist is quite significant in affecting fuel consumption. Other improvements were found to be not so significant under these circumstances as might have been expected. For example, the use of lightweight equipment did not save as much fuel as expected; therefore, the premium price for such cars appeared difficult to justify. Track rigidity was found to be a significant factor in fuel consumption, but the potential for saving fuel was not great in this country, since track is already rigid by world standards. Improvements in the design of trucks and bearings were found to result in modest savings.

Because the previous work had been restricted to level tangent track, a computer program was devised that would permit computation of the fuel consumption of a given train when operated over any track the characteristics of which are known. In addition, the results from wind-tunnel tests on blocks that simulated railroad vehicles were incorporated into the aerodynamic-drag calculation. Fifty-two runs of different but representative types of trains--such as coal trains, intermodal trains, and average consists--were simulated over real track.

It was found that the conclusions were not the same as before when level tangent track was used and that fuel consumption is heavily weighted by factors other than train resistance. In most cases examined, both the absolute savings in fuel and the percentage of savings were noticeably different from previous savings. In many cases, the magnitude of the fuel savings was highly dependent on the types of operation--low or high speed, empty or loaded train, comparatively straight and level track versus complex track that has many grades and curves, and changes in speed limits. In certain cases it was shown that reduction of track resistance on half the trip is equivalent to merely increasing braking requirements and that no savings are affected. Savings by using lightweight equipment in most instances were shown to be considerably more favorable when operations were over complex track. In general it was found that fuel savings appear highly sensitive to the type of operation. Because of this apparent sensitivity, it was recommended that this program or a similar one be used to analyze a particular operation in detail before investment decisions are made (11).

As a result of the completed and ongoing analytical studies discussed above, FRA conducted workshops on energy management in November 1979 and November 1980 so that the railroad industry could explain further the applications of the various computer programs and train-performance calculators to specific operating conditions for improved energy use.

Aerodynamic Investigations

The aerodynamic forces of importance to freight train operations are primarily the axial force and secondarily the side forces and rolling moments. At high speed (60 mph), the train's aerodynamic resistance while running at constant speed on a level track is about half the entire train resistance. The fuel expended to overcome aerodynamic resistance is 0.04 gal/car mile at 60 mph. The information available on the aerodynamic forces on freight trains has been quite limited and much of it is conflicting. The recent investigations consisted of several phases and were carried out over a period of five years.

After evaluation of different testing techniques, it was determined that a wind tunnel was the best way of making a large number of tests on many different configurations for a reasonable expenditure of time and money. In order to gain a basic understanding of the aerodynamics of a train of cars, tests were run on a series of blocks in which the effect of spacing and size was examined. To study real railroad configurations, tests were run on railroad-car models. These were models of real and proposed cars. A scale of 1:43 was selected in order to be compatible with wind-tunnel size and to take advantage of model kits available in this scale. Most tests consisted of a train of five units: a locomotive, three test vehicles, and a final car. This train was approximately 10 ft long. It was tested by using a ground plane in a wind tunnel 10 ft in diameter. The six components of force and moment were measured on the middle car of this train. The three middle cars in the configuration were varied in order to obtain measurements on different cars in different relations to each other. Tests were run on different TOFC and container-on-flatcar (COFC) configurations, both existing and developmental. Different freight cars--of the type most used by the railroads--have also been tested. These cars were tested both with trains of like cars and with various combinations of other cars (12,13).

In order to relate the wind-tunnel tests to real situations, some full-scale tests were run on actual TOFC configurations. These tests were run at the Transportation Test Center, Pueblo. Two trailers were mounted on a Trailer Train TTX car in such a way that the forces applied to the trailers could be measured by load cells. The train was then driven over a selected section of straight track at approximately constant speed. After corrections had been made for grade and acceleration, the only remaining forces on the trailers were aerodynamic. This experiment had to be performed with considerable care in order to minimize the oscillating forces, and the data had to be processed to remove these components. After the techniques had been developed, reliable results were obtained (14).

At the completion of this program, considerable understanding of the aerodynamics of freight trains had been achieved. The full-scale results substantiate that the wind tunnel is a meaningful way of conducting aerodynamic testing (15). There are several aspects that have important effects on the aerodynamic resistance. Cross winds cause major increases in the aerodynamic resistance of the train, and an accurate prediction of the aerodynamic resistance cannot be made without knowing the magnitude and direction of the wind. Open spaces in the train are very important. At low cross-wind conditions, the spacing between cars has to exceed about half the width of the car before an appreciable increase in resistance occurs. Between-car spacings are generally small enough so that closer spacings would not be a major advantage except for high cross-wind conditions. Larger openings in the train, such as an unloaded flatcar between two other cars or trailers missing from TOFC configurations, cause large effects. Other open spaces in the train, such as that between trailers and the body of the TTX car, are also important contributors to resistance. Open unloaded cars such as hopper cars are also important causes of resistance. The resistance of an unloaded bulkhead flatcar was found to be very large. Tests of different TOFC models demonstrated the difficulties caused by trying to provide flexibility to carry different loads. Systems designed to accommodate 45-ft trailers had appreciably higher resistance when loaded with 40-ft trailers.

Lightweight-Flatcar Evaluation Project

While recognizing that rolling stock of lower tare weight would reduce the load on track structures and fuel consumption, the many parties at interest have always been concerned about equipment survivability in the railroad environment. Accordingly, this project was designed to compare two prototype skeleton flatcars with the conventional Trailer Train TTAX flatcar by quantifying the acceleration environment experienced. One of the new cars was designed to carry standard containers; the other was intended to carry trailers. Both cars weigh between 20 and 30 percent less than the widely used Trailer Train car.

The evaluation was accomplished by analyzing the effect on dynamic behavior of flatcar design, load configuration, track class, vehicle speed, and mileage accumulated in service. A series of ride-vibration tests and over-the-road tests in revenue service were conducted with the cooperation of several railroads. Data were collected by using a unique accelerometer array to facilitate the study of these elastic structures by using the technique of modal analysis. The key design difference was outboard major longitudinal members versus the conventional single beam on centerline.

The modal-analysis technique proved successful, and the results (16) have already been used by car designers. Equipment of lower tare weight will appear in our national fleet in the years ahead. As an example, the joint industry-government Track Train Dynamics Project is now in the process of seeking bids on the design of a new low-tare high-cube covered hopper.

Lightweight Low-Profile TOFC Rail Vehicle Project

A major constraint on growth of TOFC service in the Northeast has been clearance restrictions along the Northeast Corridor, notably in Washington, Baltimore, and New York. In concept, a lightweight, low-profile vehicle would improve the ratio of payload to weight, reduce aerodynamic drag, and eliminate circuitous routing. Further, shippers would obtain improved service, reduced drayage expense, reduced transit times, and greater schedule reliability. Finally, communities would benefit from reduced road congestion, reduced air and noise pollution, and reduced highway maintenance costs.

Congress directed FRA to sponsor the design, construction, and testing of a prototype intermodal railcar to meet the above needs. Additional requirements for the vehicle were full interchangeability and acceptable levels of life-cycle costs. Analysis of the physical and performance characteristics were coupled with the recommendations from railroads, car builders, component suppliers, and public agencies. The resulting preliminary specification was reviewed at an industry conference and modified slightly.

At this time, due to the extensive number of innovative railcars under development or already on the market, FRA has suspended further activity on the production and evaluation of actual prototypes. Some of the emerging equipment, however, does reflect the content of the performance specification.

CONCLUDING REMARKS

The research projects described above have been supported by limited federal funds; in parallel, many other efforts are ongoing in the private firms of the suppliers and railroad operators. Although much has been learned, much remains to be learned and implemented to achieve significant conservation.

In addition to investigating fuel and its use per se, there are a number of related and interdependent areas in which research and development ultimately will contribute to petroleum conservation. Rolling stock that has a lighter tare weight and radial trucks are examples of mechanical equipment changes that will conserve energy. The electrification of high-density freight lines will at least allow the option of using some energy source other than petroleum. And, of course, improvements in car use produce a side benefit of conservation. Finally, although difficult to quantify, the gradual improvement of the nation's track structure must surely make a contribution to our conservation efforts.

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