FREIGHT WING

TYPE II CLASS EIGHT SEMI TRAILER AERODYNAMIC FUEL ECONOMY COMPARISON TEST

Conducted by:

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TABLE OF CONTENTS

1.0 OBJECTIVE

Freight Wing contracted Transportation Research Center Inc. (TRC Inc.) to perform fuel economy testing according to the requirements of SAE Recommended Practice J1321 "Joint TMC/SAE Fuel Consumption Test Procedure -- Type II." The testing served to compare the fuel economy effects of six aerodynamic configurations of a semi trailer.

2.0 APPROACH

The following equipment was tested on the test vehicle. The specific equipment combinations tested in each segment are listed in the following section, "Summary of Results":

- A fairing over the upper portion of the semi trailer's front surface.
- Left and right fairings over the doors at the rear of the trailer.
- Belly fairings mounted lengthwise below the left and right trailer edges.

TRC Inc. supplied two identical Fruehauf van trailers and two identical Freightliner Columbia semi tractors. These tractors and trailers were randomly paired together and the resulting tractor/trailer combinations were designated as either test or control vehicles. These combinations remained paired together through the duration of the program. TRC Inc. also provided instrumentation, two test drivers, technical support, test fuel, ballast for both trailers, and computer hardware and software for data reduction.

The test consisted of five test segments, one each for testing a particular combination of aero components, and a baseline segment in which all fairings were removed from the trailer. All testing was conducted at a cruising speed of 65 mph. Each test segment consisted of at least three test runs, three of which met the Type II validation requirements. All testing was conducted on the TRC 7.5-mile test track. Each test run consisted of six laps of the track, or a distance of 45.04 miles. The test and control vehicles operated concurrently on all test runs. The control vehicle served as an unchanging standard to which each test configuration could be compared through the calculation of test-vehicle-to-control-vehicle fuel consumption ratios.

Fuel consumption was measured using portable "gravimetric" fuel tanks that could be quickly disconnected from the vehicle fuel system and removed from the tractor for weighing before and after each run.

One driver and one tractor were designated to operate with the test trailer throughout all three segments of the program and the other driver and tractor were designated to operate with the control trailer throughout the entire program. These driver/tractor/trailer combinations were kept constant throughout the test program so as to minimize variability caused by tractor differences or differences in driving technique. In each segment, as many test runs as necessary were conducted until three runs met the following criteria:

- A total spread in the test vehicle / control vehicle fuel consumption ratios (T/C ratios) not exceeding two percent of the highest of the three ratios
- Over the same three runs, each truck had a variation in run times of not greater than plus or minus one-half percent.

3.0 SUMMARY OF RESULTS

The table below summarizes the fuel economy results. Complete raw data, including weather conditions can be found in Appendix A.

Percentage of fuel saved = (Ave. baseline T/C ratio – Ave. test T/C ratio) / Ave. baseline T/C ratio x 100

Segment Number and Description		Average T/C Ratio	Fuel Saved	Description of Comparison	Test Vehicle MPG
1	Baseline Vehicle	0.9702	**0.0%**	N/A	**6.07**
2	Front, Rear, and Belly Fairings	0.9029	**6.94%**	Compared to Baseline Segment 3	**6.52**
3	Front and Belly Fairings	0.9121	**5.99%**	Compared to Baseline Segment 3	**6.45**
4	Belly Fairing Only	0.9327	**3.87%**	Compared to Baseline Segment 3	**6.31**

Calculation of test vehicle miles per gallon: Actual miles per gallon measured during an individual test segment are unreliable since fuel economy values will vary greatly with day-to-day weather variations, and the Type II test procedure makes no attempt to correct for these variations. The method specified by the Type II procedure and used here is to, first, determine a representative mpg of the control vehicle. This value is calculated for all runs of the entire program that met the validation requirements stated previously. Then, the control vehicle representative mpg is divided by the average T/C ratio for each test segment to determine the mpg for the test vehicle on that segment. This result is valid only under the average conditions that existed during the times testing was actually conducted and may vary under different conditions.

The data used in calculation of the control vehicle representative mpg were:
Distance traveled on 19 validated test runs = 855.76 miles
Weight of fuel consumed on the same validated runs = 1017.52 pounds
Measured density of fuel used during the same runs = 7.00 pounds/gallon
= 855.76 miles / (1017.52 pounds / (7.00 lbs./ gallon)) = **5.887 mpg**

4.0 DESCRIPTION OF TEST VEHICLES

More detailed vehicle specifications can be found in the Type II test Data Form # 1 (Vehicle Identification) in Appendix B

TRACTORS and TRAILERS

	Control Tractor	Test Tractor	Control Trailer	Test Trailer
TRC INC. Unit #	450	451	450T	451T
MAKE	Freightliner	Freightliner	Fruehauf	Fruehauf
MODEL	CL120645ST	CL120645ST	FBHLP91.5NF2-53W	FBHLP91.5NF2-53W
V.I.N.	1FUJA6AS54L M65052	1FUJA6AS94L M26223	1H2V05328TE050319	1H2V05328TE050319
MODEL YEAR	2003	2003	1994	1996
ENGINE	Cat C-12	Cat C-12	N/A	N/A
START ODOMETER	49,460	94,614	95,325	N/A
TIRES -- STEER	Bridgestone R299 295/75R22.5	Bridgestone R299 295/75R22.5	N/A	N/A
TIRES – DRIVE/TRAILER	Bridgestone M726 295/75R22.5	Bridgestone M726 295/75R22.5	Recaps on Bridgestone R194 casings 295/75R22.5	Recaps on Bridgestone R194 casings 295/75R22.5
TRANSMISSION	Eaton Fuller FRO 14210C	Eaton Fuller FRO 14210C	N/A	N/A
DRIVE AXLE RATIO	3.73	3.73	N/A	N/A
TEST WEIGHT W/TRAILER	65,000 lbs.	65,000 lbs.	--	--

5.0 INSTRUMENTATION

ITEM	DESCRIPTION	PURPOSE	CALIBRATION
Radar Gun	Stalker Pro	Vehicle speedometer calibration before testing	Within TRC Inc. ISO 9001 periodic calibration interval
Gravimetric Fuel Tanks	15-gallon fuel cells (Total of 4)	Supplied fuel during test.	Calibration not applicable.
300-lb. Scale	Accuweigh 301 TDX	Weighed gravimetric tanks to .01 lbs. resolution,	Calibrated daily with F-class calibration weights
Calibration Weights	50-pound, F-class (Total of 2)	Daily calibration of scales	Within TRC Inc. ISO 9001 periodic calibration interval
Hydrometer/ Thermometer unit	Fisher model 116035	Measured temperature and density of test fuel.	Within TRC Inc. ISO 9001 periodic calibration interval

6.0 VEHICLE PREPARATION

- Steer, drive, and trailer axles were aligned to manufacturer's specifications. Tractor and trailer axle bearing and brake adjustments were checked at this time.

- The tractor speedometer calibrations were confirmed by radar.

- The fifth wheels of both tractors were adjusted so that the back-of-cab-to-front-of trailer gap was 47 +/- ½ inches (127 cm).

- The bogeys of both trailers were set to the third adjusting hole from the forward most adjustment point (about1/5 of their adjustment travel behind the forward-most point).

- The trailers were loaded to provide gross combined test weights of 65,000 +/- 50 pounds.

- A gravimetric fuel system, consisting of a gravimetric fuel tank and quick-disconnect couplers for supply and return was installed on each truck.

- The tires were set to cold pressures of 110 psi (steer) and 100 psi (drive and trail) immediately before the start of warm-up prior to each test day.
- The engine cooling fans and air conditioning compressors were disabled to prevent inconsistent operation during test.
- Documentation of vehicle equipment was completed.
- The gravimetric fuel tanks were drained and refilled with test fuel of known density (British Petroleum, Diesel Supreme). A dedicated supply of this fuel was established for use throughout the test program.

Vehicle preparation and inspection documentation are found in Appendix B

7.0 DESCRIPTION OF TEST FACILITY

Testing was conducted on the TRC 7.5-mile oval test track. This track consists of three 12-foot-wide lanes constructed of Portland cement concrete. Additional 12-foot lanes of asphalt, one inside and one outside the concrete lanes, allow for slower traffic and for braking maneuvers.

The track has a 180-degree turn at each end. Each turn has a radius of 2,400 feet and a travel distance of 1.75 miles. The turns have parabolic banking. This testing was restricted in the turns to the lowest concrete lane, which has an average banking of 10 degrees. The trucks participating in this test were given special priority to ensure they would not need to pass slower traffic in the turns.

Two straight sections, each 2.0 miles in length, connect the turns. The straight sections have a slope of .228 percent from north to south. When necessary the trucks were allowed to travel into the second concrete lane in the straight sections to pass slower traffic.

The track has a pit lane located adjacent to the northbound straight section. Changing and weighing of fuel tanks and computing of results occurred at the pit lane.
Average elevation of the track is 1,086 feet above sea level. Track diagrams can be found in Appendix D.

8.0 TEST PROCEDURE

8.1 General

Testing was conducted in accordance with the requirements of the Joint TMC/SAE Fuel Consumption In-Service Test Procedure Type II. The test consisted of one baseline segment and three test segments. Each segment consisted of at least three test runs, three of which met the validation criteria of the Type II standard. Due to logistics of installation and removal of the tested fairings, testing of the baseline segment was conducted before testing of the three test segments.

The baseline segment was conducted in wind conditions that were lighter than was encountered in some later test segments. To verify this baseline segment was a valid comparison to segments conducted in higher winds, an additional baseline run was conducted after the test vehicle was returned to baseline condition after the final test segment and while the wind speed was still approximately 20 mph. The additional run was found to correlate near the average of the three runs conducted previously and was included in the baseline segment data. Thus, the baseline segment consists of four valid runs.

The two drivers were randomly designated for either the test or control trailer and the tractors were designated as either test or control tractors. Once designated, a driver, tractor, and trailer combination operated together throughout all segments of the test.

The installation, removal, and weighing of gravimetric tanks occurred in the pit lane of the TRC 7.5-mile track.

The drivers accelerated the trucks to cruising speed at maximum power. The manually shifted transmissions in both vehicles were shifted at 1,900 rpm. The trucks cruised in top gear at the cruising speed of 65 miles per hour. The cruising speeds were maintained by use of cruise control.

The Type II procedure requires recording of weather data but does not establish weather limits. Testing may be conducted under any weather conditions that will allow suitably consistent results. Ambient temperature, wind speed, wind direction, humidity, and barometric pressure were recorded via the TRC weather station. This weather station is calibrated to TRC Inc's ISO 9001 standards. Weather data can be found in Appendix A.

8.2 Pre-test Inspection and Warm-up

Each morning, immediately before vehicle warm-up driving was begun, all truck tires were set to the specified pressures (110 psi on steer axles and 100 psi on drive and trail axles). Mirrors were adjusted to a consistent position between the two tractors. Headlights were turned on and switched to low beam. Heater blowers were operated at medium speed. Other switchable electrical loads were turned off

The trucks were warmed up each test day by being driven for one hour on the TRC 7.5-mile track at 65 miles per hour. Members of the test crew drove the trucks through additional laps to keep the trucks warm whenever the test drivers took lunch or other breaks during the test day. During warm-up laps, the trucks were fueled from dedicated portable tanks. This prevented any need to valve the main vehicle tanks into the fuel system at any time during the test day and made for improved fuel measurement consistency. The drivers made use of warm-up driving on the first test day to agree upon suitable end-of-run deceleration and braking points.

8.3 Fuel and Time Measurement

8.3.1 General

Fuel consumption for each vehicle was measured for each run completed. Consumption, measured in pounds, was determined by weighing a portable fuel tank prior to and immediately following each test run. The 15-gallon portable, or gravimetric, fuel tanks were equipped with quick disconnect couplings on supply and return lines for easy removal and installation to the vehicle fuel system. Tanks were weighed utilizing a portable triple-beam balance scale having a resolution of .01 pound. (Scale accuracy was verified daily prior to tank weighing using two "F" classification 50-lb. calibration weights.)

Two dedicated gravimetric tanks for each vehicle were weighed and alternated between runs to lessen vehicle down time and cool-down periods between runs.

8.3.2 Chronological Procedure

During the morning warm up, each truck's designated "number one" tank was filled, the tank fittings were purged of any air, and the tank was weighed. After completion of the warm-up, and after stopping the engines, each truck's warm-up tank was removed from the truck, the pre-weighed, number one tank was then installed on the truck and the hoses were connected.

The truck was then started on a six-lap (45.04-mile) test run. As the engine started, both the driver and the test coordinator started stopwatches. The driver waited 20 seconds with the engine idling to allow time for engaging the starting gear.

At the end of the test run, the driver stopped the truck at a pre-designated point in the track pit lane. The driver again allowed the engine to idle for 20 seconds, to allow time for stabilizing of fuel pressure. Both the driver and test coordinator stopped their stopwatches as the engine stopped. The total run time, including idle time, recorded by the test coordinator was recorded as the official run time. The driver's run time served as a back up in case of error or confusion in the coordinators recorded time.

The number-one tank was then removed and weighed as detailed previously. Tank weights and run times were recorded into a computer spreadsheet and on a back-up paper form.

The number-two tank -- filled, purged, and weighed while the previous run was in progress, -- was installed and another run was begun.

Detailed fuel consumption and run time data can be found in Appendix A.

8.4 Test Fuel

A single dedicated stock of type D2 diesel fuel was used throughout the program. This fuel was taken from a standard fuel delivery to TRC. TRC Inc's gravimetric test tanks were emptied and then filled from this fuel batch. The fuel was tested for density at 60 degrees F. The density was found to be 7.00 pounds per gallon. A fuel density calculation sheet can be found in Appendix B.

9.0 DATA REDUCTION

After each test run had been completed and weight of the fuel consumed by each truck on that run had been determined, the weight of fuel consumed by the test tractor was divided by the weight of fuel consumed by the Control tractor. The resulting quotient is termed a Test/Control ratio, or T/C ratio. The Type II test procedure requires that a sufficient number of test runs be made until three test runs meet the following criteria:

- A total spread in the T/C fuel consumption ratios not exceeding two percent of the highest of the three ratios
- Over the same three runs, each truck had a variation in run times of not greater than plus/minus one-half percent.

After baseline and test segments were completed for all configurations, final results were calculated as follows:

• Percentage of fuel saved in each configuration's test segment compared to the segment appropriate to be used as its baseline.

(Ave. baseline T/C – Ave. test T/C) / Ave. baseline T/C

Values calculated for percentage of fuel saved of the test segment over the baseline segment can be reported as either positive or negative.

Additional calculations were made to determine a fuel economy (mpg) value of the test vehicle for each segment. This was done by calculating a representative mpg value for the control vehicle using all test runs that were validated in any segment of the program. The control vehicle representative mpg was then divided by the average T/C ratio from each segment to establish the test vehicle mpg for that configuration. This approach compensates for variations in weather conditions by normalizing the fuel economy performance of the test vehicle in all segments to the average weather conditions experienced by the control vehicle over the longer duration. Data used in calculation of the test vehicle mpg is found in section 3.0 "Summary of Results".

Raw data with test run validations and weather data can be found in Appendix A.

10.0 CONCLUSIONS

Examination of the test data allows the following conclusions to be drawn:

- All test configurations produced fuel savings that exceeded the stated plus-or-minus one percent uncertainty of the Type II test procedure.
- The belly fairing made the greatest improvement in fuel savings and when used in conjunction with front and rear fairings enabled greater fuel savings from the front or rear fairings than those fairings achieved when tested without the belly fairing.