NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering

Washington, D.C. 20594

November 7, 2008

Vehicle Dynamics Study

NTSB Case Number:

HWY-08-MH012

A. ACCIDENT

Location:	Mexican Hat, UT
Date:	January 6, 2008
Time:	8:02 PM MST
Vehicle:	2007 MCI Model J4500, 56-Passenger Motorcoach

B. AUTHOR

Dan T. Horak
NTSB
(202) 314-6664
Email: dan.horak@ntsb.gov

C. ACCIDENT SUMMARY

On January 6, 2008, at about 3:30 PM MST, a 2007 MCI 56-passenger motorcoach with 51 passengers on board departed Telluride, CO en route to Phoenix, AZ, as part of a 17-motorcoach charter. The motorcoach was returning from a three-day weekend of skiing. The vehicle was diverted to an alternate route that included US Routes 191 and 163 in Utah, due to the closure of Colorado State Route 145 because of snow. Colorado State Route 145 is the normal route used from Telluride to Phoenix.

At about 8:02 PM MST, the motorcoach was traveling southbound on US Route 163 descending a 5 percent grade leading to a curve to the left, 1,800 feet north of milepost 29. After entering the curve, the motorcoach departed the roadway at a shallow angle striking the guardrail with the right rear wheel about 61 feet before the end of the guardrail.

The motorcoach began rotating in a counterclockwise direction as it descended an embankment. It began to overturn and struck several rocks in a creek bed at the bottom of the embankment. The motorcoach came to rest on its wheels after overturning 360 degrees. During the rollover sequence, the entire roof of the motorcoach separated from the body, and 50 of the 52 occupants were ejected. As a result, nine passengers were fatally injured, and 42 passengers and the driver received various degrees of injuries from minor to critical.

The weather in Mexican Hat was cloudy and the roadway was dry at the time of the accident.

D. DETAILS OF INVESTIGATION

The purpose of this investigation was to estimate the maximum speed the motorcoach in the Mexican Hat, UT accident could have reached with the fuel shut off because the vehicle speed limit was exceeded. The estimate is based on analysis of the dynamics of the motorcoach on the downgrade leading to the accident site.

Physical Parameters

Road Grade

The road leading to the accident curve slopes down at the average grade of 4% for 6400 ft. The slope just before the accident curve is 5.6%. Over the last 1000 ft, the slope gradually decreases from over 5% to about 3% at the point where the coach departed the road.

Vehicle Parameters

Mass: 24516 kg (equal to GVWR of 54000 lb)

Frontal Area: 9.27 m^2 (2.59 x 3.58)

Aerodynamic Drag Coefficient C_D: 0.6 (nominal value)

Tire Rolling Resistance Coefficient C_r: 0.01 (nominal value)

Other Parameters

Air Density: 1.19 kg/m^3 (at elevation of 4400 ft and at 39°F)

Uncertainty of Parameter Values

The aerodynamic drag coefficient C_D is not known accurately for this motorcoach. It is usually assumed to be 0.6 for trucks. We consider the range from 0.5 to 0.7 in this report. The value of 0.5 could be the most appropriate for this aerodynamically-shaped vehicle (as opposed to a truck). The high value of 0.7 can be viewed as adding engine and transmission frictional drag torques to the aerodynamic drag force term.

The simple formula for aerodynamic drag force that uses C_D and is used in this report is only an approximation. Experiments involving the exact motorcoach model would be required to provide accurate values of the aerodynamic drag force at various speeds.

The tire rolling resistance coefficient C_r is not known accurately for the tires and axle loads of this specific vehicle. It is usually assumed to be 0.01. We consider the values of 0.01 and 0.02 in this report. The high value of 0.02 can be viewed as adding engine and transmission frictional drag torques to the tire rolling resistance term, and accounting for higher tire rolling resistance at high speeds.

Model of Vehicle Dynamics

The vehicle acceleration on a downgrade is determined by gravity force that increases it and drag forces that decrease it. The acceleration is given by Eq. (1).

$$a = (F_g - F_D - F_r)/M \qquad (1)$$

where

a	vehicle acceleration	
F_g	gravity force	$F_g = Mg\sin(s)$
F_D	aerodynamic drag force	$F_D = \rho C_D V^2 A/2$
F_r	tire rolling resistance force	$F_r = MgC_r$
M	mass of vehicle	
g	acceleration of gravity (9.81 m/s^2)	
s	slope (e.g., 0.05 for 5% downgrade)	
ρ	air density	
A	frontal area of vehicle	
V	vehicle speed	

Analysis of Motorcoach Acceleration on the Downgrade Leading to the Accident Site

The acceleration was estimated for the case where the motorcoach enters the downgrade segment of the road with an initial speed and continues moving with the fuel shut off. The following parameters were used in a simulation based on Eq. (1).

s = 0.045 (downgrade of 4.5%)

C_D = 0.6

C_r = 0.01

Initial speed = 70 mph

No engine torque

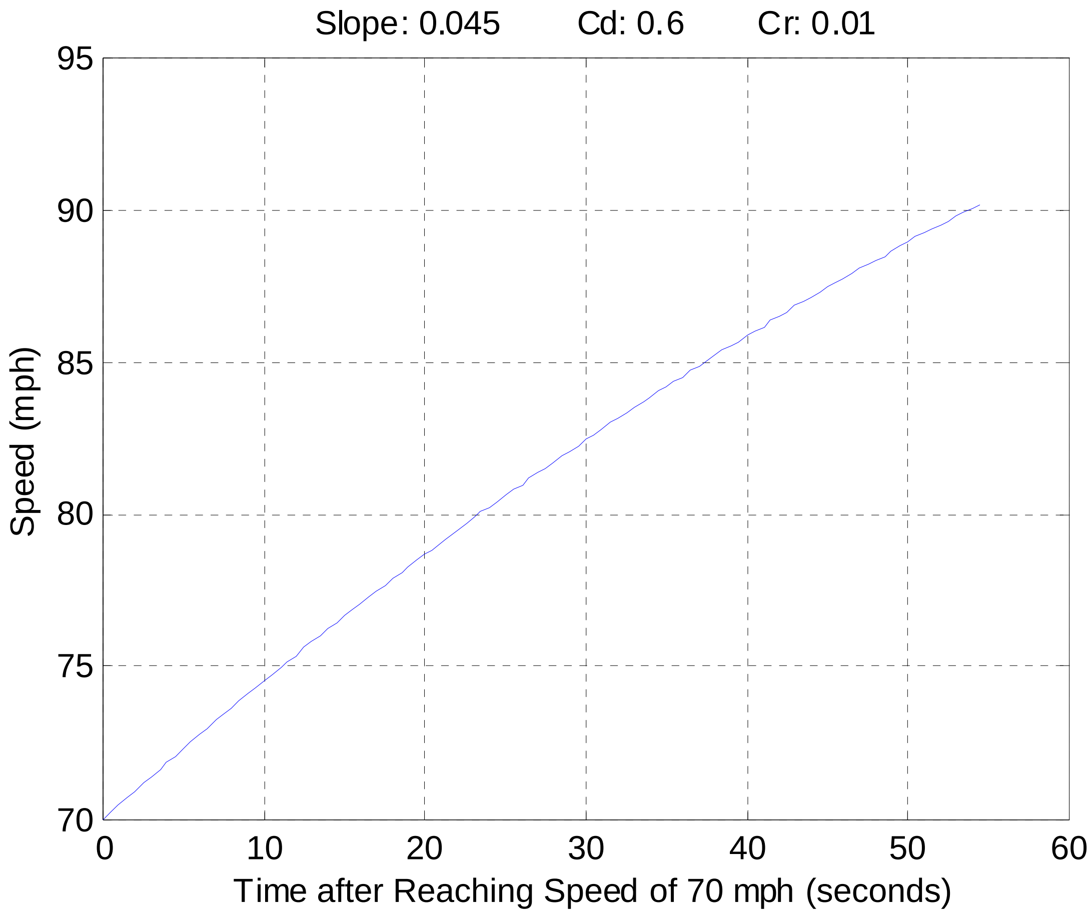

Figure 1 Speed Increase from 70 mph vs. Time (with fuel shut off)

Figure 1 shows that the motorcoach reached the speed of 90 mph in 54 seconds when started at 70 mph on a 4.5% downgrade. Figure 2 shows that the distance traveled when the speed reached 90 mph was 6400 ft. These results indicate that the motorcoach can reach speeds significantly higher than the fuel cut-off speed when traveling on a 4.5% downgrade.

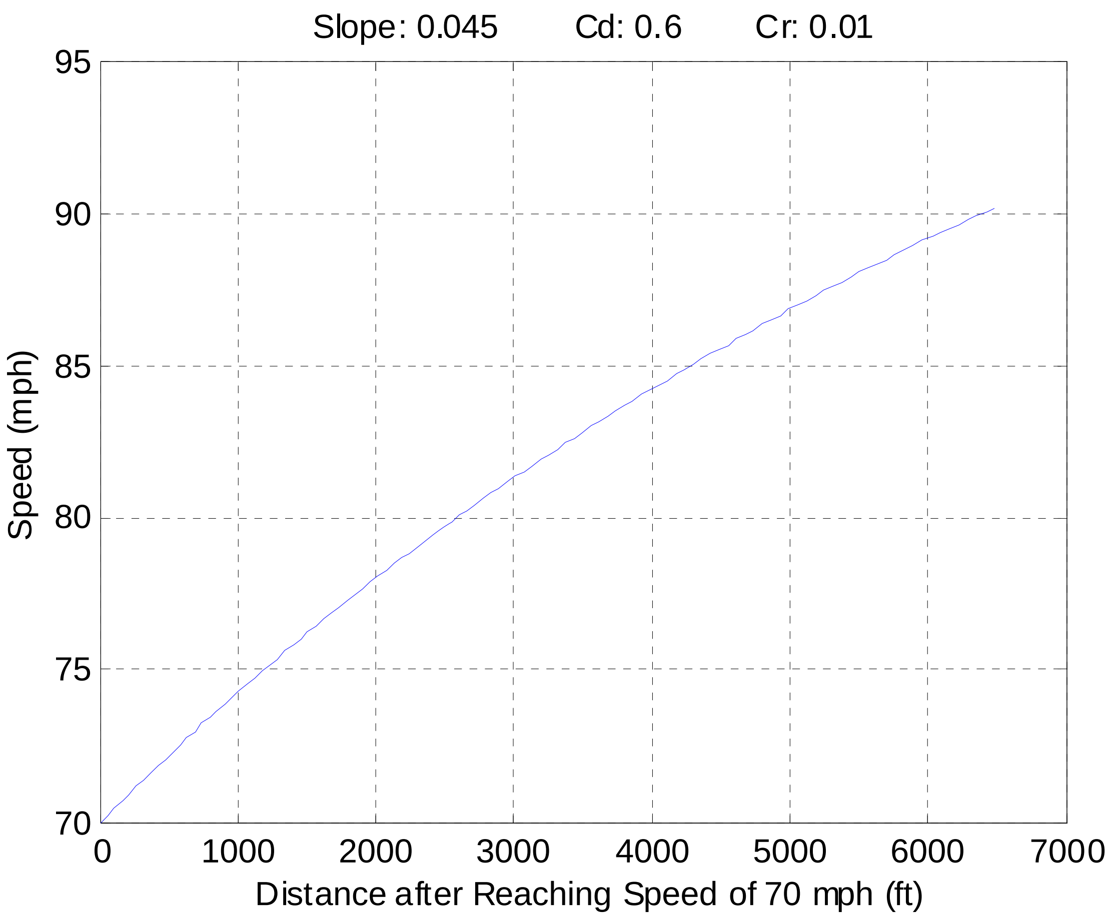

Figure 2 Speed Increase from 70 mph vs. Distance (with fuel shut off)

Analysis of Motorcoach Decelaration due to Reduced Downgrade at Accident Site

On the 1000 ft long road segment before the point of road departure, the road downgrade is reduced from about 5% to about 3%. Simulations were performed to estimate the vehicle deceleration due to such downgrade reduction. The simulations were performed for the case when the motorcoach entered a road segment with a reduced downgrade at an initial speed and the fuel shut off. The following parameters were used in a simulation based on Eq. (1).

s = 0.03 (downgrade of 3%)

C_D = 0.6

C_r = 0.01

Initial speed = 88 mph

No engine torque

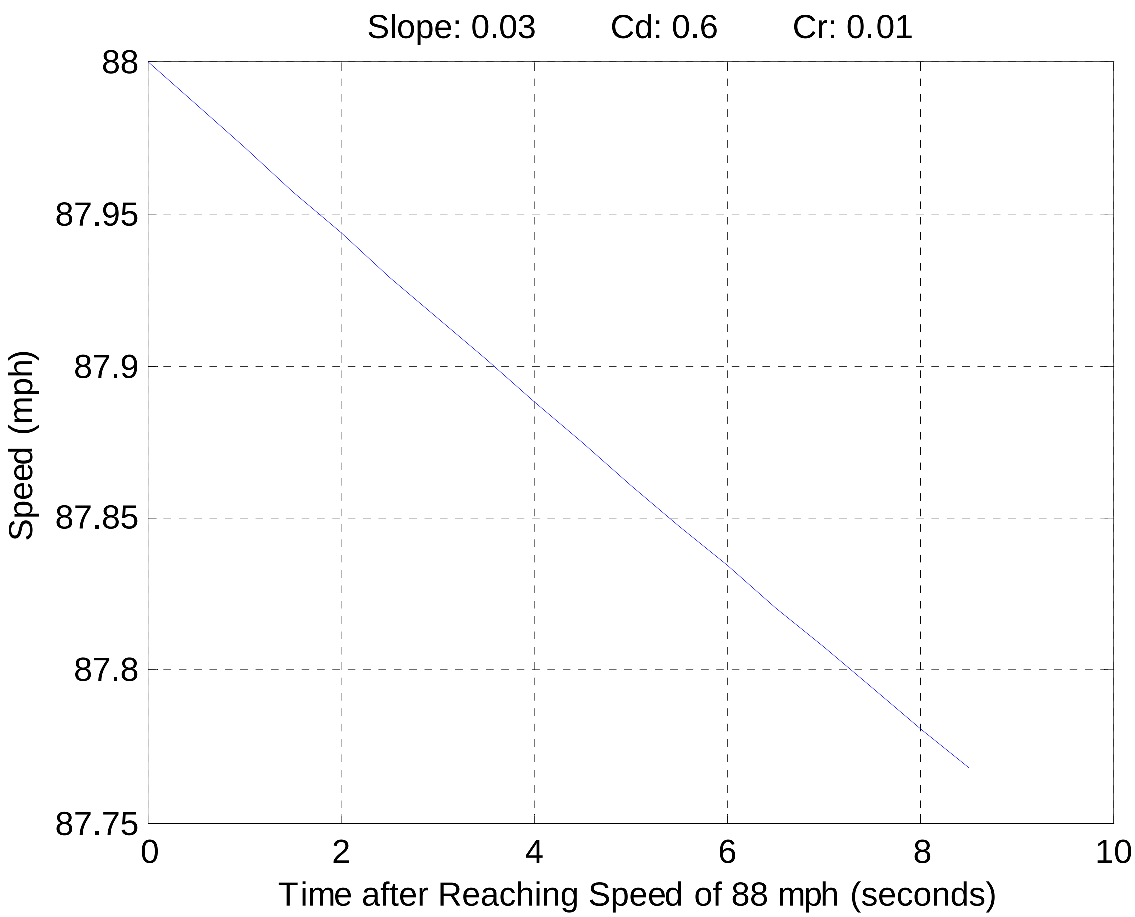

Figure 3 Speed Decrease from 88 mph vs. Time (on a 3% downgrade)

Figure 3 shows that in 1000 ft on a 3% downgrade, the motorcoach will slow down by less than 0.2 mph when started at 88 mph. The simulation assumed a constant 3% downgrade. On a downgrade where the slope is reduced gradually from 5% to 3%, the deceleration would have been even lower. This agrees with the DriveCam vehicle-mounted camera longitudinal accelerometer that did not show a measurable deceleration.

Terminal Velocity Analysis of the Motorcoach

Terminal velocity is the steady-state (and maximum) velocity that a vehicle reaches on a downgrade, when gravity force is balanced by aerodynamic drag forces, tire rolling resistance forces, and frictional forces in the engine and the transmission. Engine torque is set to 0 because the fuel is assumed to be shut off at high speeds.

Table 1 shows the terminal velocity for ranges of parameters. Note the row shown in red. It corresponds approximately to the road downgrade leading to the accident and to high values of the aerodynamic drag coefficient (C_D=0.7) and the rolling resistance coefficient (C_r=0.02). The terminal velocity of the motorcoach is 96.7 mph. This value is considered the nominal terminal velocity estimate for this case. When moving at this speed, the motorcoach dissipates 278 HP due to tire rolling resistance and 418 HP due to aerodynamic drag.

If the nominal values of the aerodynamic drag coefficient and the rolling resistance coefficient were used, i.e., C_D=0.6 and C_r=0.01, the dissipation due to tire rolling resistance would have been 139 HP and the dissipation due to aerodynamic drag would have been 358 HP at the speed of 96.7 mph. Therefore, the use of high values of C_D and C_r, intended to account for frictional drag torques in the engine and the transmission, increased the total energy dissipation by 199 HP (because 278+418-139-358=199). This is considered more than what the engine and the transmission actually dissipate due to friction. Therefore, the actual terminal velocity of the motorcoach is likely to be higher than the conservative estimate of 96.7 mph.

Some terminal velocities on 3% and 4% downgrades are below 88 mph. They are shown only for reference because it is known that the grade was at least 4% for 6400 ft before the accident site and was above 5% just before it.

Table 1 Terminal Velocity of the Motorcoach vs. Parameters

Downgrade	**C_D**	**C_r**	**Terminal Velocity (mph)**
5%	0.5	0.01	132.1
5%	0.5	0.02	114.4
5%	0.6	0.01	120.6
5%	0.6	0.02	104.4
5%	0.7	0.01	111.7
5%	*0.7*	*0.02*	*96.7*
4%	0.5	0.01	114.4
4%	0.5	0.02	93.4
4%	0.6	0.01	104.4
4%	0.6	0.02	85.3
4%	0.7	0.01	96.7
4%	0.7	0.02	79.0
3%	0.5	0.01	93.4
3%	0.5	0.02	66.1
3%	0.6	0.01	85.3
3%	0.6	0.02	60.3
3%	0.7	0.01	79.0
3%	0.7	0.02	55.8

E. CONCLUSIONS

The analysis described in this report resulted in a terminal velocity estimate of 96.7 mph for the motorcoach in the Mexican Hat, UT accident. Aerodynamic drag forces, tire rolling resistance forces and frictional drag torques in the engine and the transmission were considered in deriving this velocity estimate.

Although this analysis considered reasonable ranges of parameter values for this vehicle, the actual parameter values for this specific vehicle could be outside of these ranges. Additionally, the dependence of the drag forces on speed can deviate significantly from the expressions used here. Therefore, all the results presented in this report should be viewed only as estimates derived based on acceptable engineering practices.