

Acceleration and Braking Performance of Snowmobiles on Groomed/Packed Snow

2011-01-0287

Published
04/12/2011

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doi:[10.4271/2011-01-0287](https://doi.org/10.4271/2011-01-0287)

ABSTRACT

There are limited scientific data available on the acceleration and braking performance of modern snowmobiles. In this study we investigated the acceleration and deceleration characteristics of four modern snowmobiles of varying engine size (500 to 1000 cc) and style (2-stroke and 4-stroke) on groomed/packed snow conditions. The acceleration tests were performed at quarter, half and full throttle. The deceleration tests were performed using full braking with locked tracks and rolldown with power both on and off. Target test speeds ranged from 20 to 60 km/h. Snow condition parameters were measured throughout the tests. The results of the acceleration tests showed that at higher speeds, higher horsepower rating generally corresponds to higher acceleration rates, with a maximum observed average acceleration of 0.70g. The results of the full braking deceleration tests found no significant difference between snowmobiles or test speed, with the range of deceleration rates ranging from 0.32 to 0.42g. Rolldown tests showed that deceleration increases with speed and that there is no significant difference between rolldown deceleration in the power on and power off conditions. These test results will allow accident reconstructionists to better quantify vehicle speeds in snowmobile incidents in similar snow conditions.

INTRODUCTION

In a study of snowmobile related injuries in North America it was found that each year there are approximately 200 deaths and 14,000 injuries associated with snowmobile accidents^[1]. Understanding the straight-line acceleration and braking performance of snowmobiles is crucial in assessing many snowmobile accidents. A snowmobile's straight-line performance differs from that of road vehicles in a number of ways. First, snowmobiles are track-driven vehicles, steered

by a set of skis. Second, snowmobiles travel primarily on snow, which can vary considerably with the environmental conditions present at the time. Third, snowmobiles can experience large amounts of weight shift during acceleration and braking due to their suspension systems. Like road vehicles, however, deceleration marks in the snow can be measured and then used to determine pre-braking or pre-rolldown speed if the deceleration rate is known. Similarly, the speed of a snowmobile can be estimated if its acceleration rate is known.

There is a lack of scientific literature quantifying snowmobile acceleration and braking performance. Previous studies have generally been conducted with older generation snowmobiles^[2, 3, 4, 5, 6]. With the recent introduction of 4-stroke engines, new data are needed. Many of the previous studies have also performed tests on various snow surface conditions, with little attention paid to keeping snow surface conditions constant between tests.

The primary objective of this study was to measure the straight-line acceleration and braking performance of various snowmobiles in groom-packed snow conditions under various throttle and braking conditions. A secondary goal was to determine whether acceleration and braking performance varied with speed. The results were then interpreted in the context of snowmobile engine type and horsepower.

METHODS

SNOWMOBILES

Four stock (unmodified) snowmobiles with different engine types (2-stroke/4-stroke) and engine power ratings (80 to 135 hp) were tested ([Table 1](#), [Figure 1](#)). Each snowmobile was fitted with its original equipment manufacturer (OEM) non-studded track. All four snowmobiles were short-track sleds

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with track lengths of 307 cm. Three of the snowmobiles had a track width of 381 mm and a track profile height of 25 mm. The Yamaha Phazer had a track width of 356 mm and a profile height of 32 mm. Both Ski-Doo snowmobiles were purchased used and were serviced by a snowmobile mechanic prior to testing. Both Yamaha snowmobiles were borrowed from a driver training facility where they were maintained on an ongoing basis. Fuel was maintained between half and full during all tests.

Table 1. Description of Snowmobiles Tested.

Sled Notation	Year	Make	Model	Engine	hp/kW (EST)	Dry Weight (kg)
S6	2004	Ski-Doo	MXZ	600 cc 2-stroke	115/86	211
S8	2003	Ski-Doo	MXZ	800cc 2-stroke	135/101	206
Y1	2009	Yamaha	RS Vector	1000cc 4-stroke	120/89	253
Y5	2009	Yamaha	Phazer RTX	500 cc 4-stroke	80/60	222



Figure 1. Test Snowmobiles.

INSTRUMENTATION

A DL2 Data Logger (Race Technology, Nottingham, England) mounted to the rear of the snowmobile was used to log onboard global positioning system (GPS) and 3-axis accelerometer data. Brake-line pressure transducers (Sensotec LM/2345-12, 20.7MPa, Columbus, OH) were installed at the master cylinder located on the left handlebar. Throttle position was measured using string potentiometers (ASM

Model WS1.1, 100mm and 500mm, ASM, Moosinning, Germany). Mechanical stops positioned under the throttle lever were used to restrict the throttle's range of motion to one quarter or one half throttle in some tests. Brake light and running light voltages were also recorded. GPS data were acquired at 20Hz and accelerometer, pressure, voltage and string potentiometer data were acquired at 100Hz using the DL2's data acquisition system.

The OEM track speed sensors on the Ski-Doo snowmobiles were also recorded by the DL2 to monitor track rotation and lockup. On the Yamaha snowmobiles, track rotation and lockup were recorded using a video camera (Aiptek Pocket DV5800, Irvine, CA) oriented so that the brake light and track were both visible. Video data was recorded at 30 frames per second, and the video was synchronized with the DL2 data using the point of brake light activation.

The snowmobiles were operated by a certified snowmobile instructor (Canada Safety Council) with 40 years experience. His mass, including clothing, was 92 kg.

TEST SITE

The tests were conducted in rural Ontario over three consecutive days in February 2010. The test area had a small constant slope for which the data was corrected. The test surface varied between freshly groomed to travelled groomed snow. The area was groomed twice daily, before both the morning and afternoon test sessions, by a Pisten Bully 200 Edge grooming tractor to replicate a freshly groomed snowmobile trail. The snow surface was monitored over the three test days using the International Classification for Seasonal Snow on the Ground (IACS, 2009). Atmospheric conditions were recorded with a portable weather station (TyconTP1080WC, Draper, UT).

Air temperature remained below freezing, except for one afternoon, where it reached a maximum of 2.9°C. Snow surface temperatures during testing varied between -7 °C and -0.4 °C. Throughout testing, the surface snow was "moist" (it had a tendency to stick together when crushed), although no water was visible, even under a magnifying glass. The hardness of the groomed snow was very soft, as defined by the International Classification for Seasonal Snow "hand test" method. Snow grains that were not broken during grooming were generally large rounded particles $\geq 0.25\text{mm}$. There was some snow precipitation during testing which was typically in the form of stellar dendrites and plates.

TEST PROCEDURE

Acceleration tests were performed at either quarter (Q), half (H) or full (F) throttle, with Q and H throttle positions corresponding to one quarter and one half of the throttle lever travel required for full throttle. The rider was instructed to rapidly apply the throttle until either the mechanical stop (in

Q and H tests only) or full throttle was reached. Throttle position was maintained until a target test speed (20, 30, 40 or 60 km/h, depending on the test) was exceeded. After the target speed was exceeded, the snowmobile was brought to rest using either full braking (FB) or one of two rolldown conditions. Full braking consisted of rapidly and maximally applying the brake lever until the snowmobile came to a complete stop. Rolldown with power on (RD_ON) consisted of releasing the throttle and allowing the snowmobile to coast to rest with the power on. Rolldown with power off (RD_OFF) consisted of releasing the throttle and simultaneously activating the stop switch, and then allowing the snowmobile to coast to rest without power. After each test, any visible deceleration track marks (locked track or rolldown) were measured. Test order was pseudo randomized across the three days to minimize the effect of changes in environmental and surface conditions.

Four main experiments and two follow-up experiments were performed. Full throttle acceleration tests to 20, 40 and 60 km/h were performed using all four snowmobiles to determine whether acceleration varied with peak speed. Acceleration tests to 30 km/h were then performed under Q, H and F throttle conditions to quantify the effect of throttle position on acceleration rate. Follow-up tests were done using three snowmobiles to examine the combined effect of throttle position (Q, H, F) and speed (30 and 60 km/h). All acceleration tests described above were repeated five times for each test condition and snowmobile.

Full braking tests from 20, 40 and 60 km/h were performed using all four snowmobiles to determine whether deceleration rates varied with speed. Deceleration tests from 30 km/h were then performed under FB, RD_ON and RD_OFF conditions. Follow-up tests were then performed using two snowmobiles to examine the combined effects of braking level (RD_ON, RD_OFF) and speed (30 and 60 km/h). All deceleration tests were started from speeds above the target speed. All deceleration tests described above were repeated four times for each test condition and snowmobile.

DATA ANALYSIS

The speed and accelerometer data reported by the DL2 were first filtered using a dual-pass, 4th order Butterworth filter with a 3 Hz and 5Hz roll-off frequency respectively (Figure 2). Average acceleration and average deceleration were calculated by dividing a change in speed by the time over which this change occurred. For the acceleration tests, start times were identified by a large continuous jump in the longitudinal accelerometer data. The end point was defined as the time the target test speed was reached. For the braking tests, the start time was defined as the time when the snowmobile speed passed through the desired test speed. The end time was defined as the inflection point in the integrated longitudinal accelerometer data. Target speeds were reached

in all but three of the 60 km/h full throttle acceleration tests, where peak speeds only reached 52 to 54 km/h, and one 60 km/h rolldown test, where peak speed only reached 55 km/h. For these tests, the actual peak speeds were used to calculate the average acceleration and deceleration.

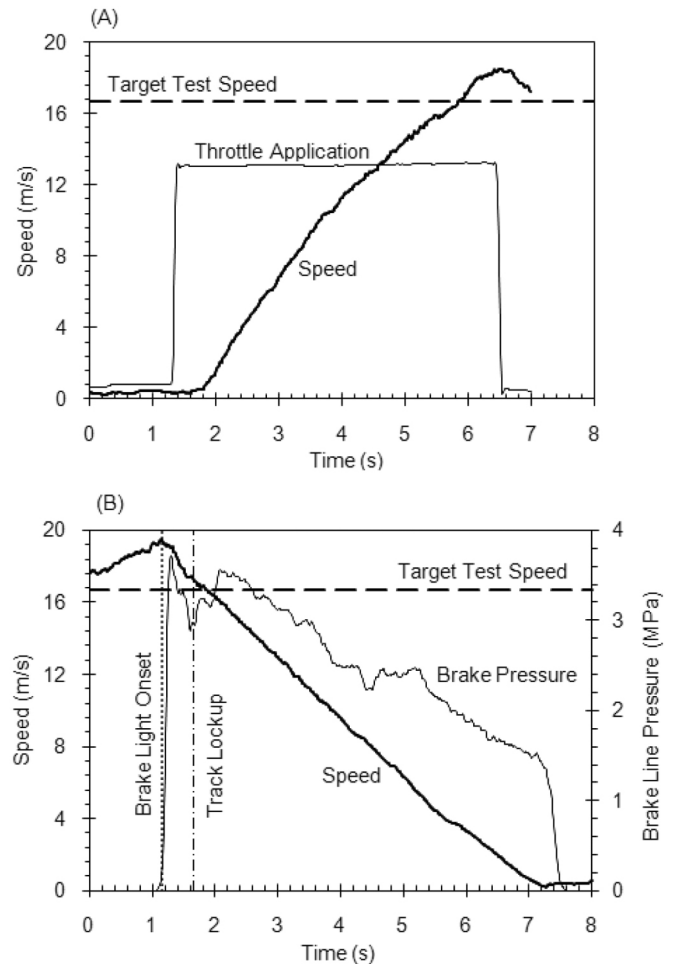


Figure 2. Exemplar data of a full throttle acceleration test (A) and a full braking deceleration test (B). The full throttle test (A) shows throttle position and speed as a function of time for the Yamaha 500. The full braking test (B) shows brake pressure and speed as a function of time for the Ski-Doo 600. The vertical lines in panel B show when the brake light illuminated and the track locked. The target speed for both tests was 60 km/h.

STATISTICAL ANALYSIS

The two dependent variables were average acceleration and average deceleration. A two-way analysis of variance (ANOVA) was used to assess the effects of sled type (S6, S8, Y1, Y5) and target speed (20, 40, 60 km/h) on full throttle acceleration. Similarly, a two-way ANOVA was used to assess how sled type and throttle position (Q, H, F) affected acceleration to 30 km/h. For the follow-up acceleration