

DETERMINATION OF SNOWMOBILE DECELERATION RATES FOR EJECTED OCCUPANT SCENARIOS

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Abstract

In collision reconstruction, skid distances are a reliable tool in helping to determine the pre-impact speed of a vehicle. When reconstructing a snowmobile accident, the 'skid-to-stop' distance of the snowmobile can similarly be used to help determine the impact speed, if the deceleration rate of the snowmobile is known. For some basic scenarios, snowmobile deceleration rates can be estimated from the literature. However, for scenarios where the snowmobile rider is ejected during impact, which is often the case (as with motorcycle or bicycle collisions), the 'coasting' deceleration rate of the unoccupied snowmobile is required. To our knowledge, this coasting deceleration rate for unoccupied snowmobiles has not been previously documented. In motorcycle or bicycle collisions, the vehicle will typically fall over and a sliding coefficient of friction can be used. However, an unoccupied snowmobile can continue gliding upright if its rider is ejected. In such cases, the snowmobile suspension would be expected to 'unload' the weight on the high-traction belt that drives the snowmobile, leaving more weight on the low-friction front skis. In this initial study using a live test subject, the deceleration of a moving snowmobile was measured when the occupant was suddenly 'thrown' from the vehicle and the snowmobile was allowed to coast to a stop. Safety measures were taken to ensure that the tests could be conducted safely. Starting speeds of up to 40 km/h were tested, both on fresh powder snow and on pre-made snowmobile tracks in powder. Control runs with no occupant ejection were also conducted at speeds of up to 90 km/h, allowing the snowmobile to coast to a stop (simulating an unconscious or stunned rider). For the 'ejected occupant' test runs, the average snowmobile coasting deceleration was 0.24 g, with 3 of the 4 test runs being 0.19 g (range of 0.19 g to 0.39 g; 1 'g' = 9.81 m/s²). For the 'unconscious occupant' test runs, the average snowmobile coasting deceleration was 0.27 g (range of 0.14 g to 0.37 g). When the results were categorized by the test speeds, other trends emerged. In particular, the coasting deceleration increased with increased speed (0.19 g avg. [SD = 0.00 g] at 26 to 33 km/h, 0.25 g avg. [SD = 0.10 g] at 40 to 60 km/h, 0.35 g avg. [SD = 0.01 g] at 90 km/h). The results of this initial research study are hereby being made available to both the public and private sector reconstruction communities to assist in analyzing snowmobile accidents. Further research is recommended to gather additional data and to extend the 'ejected' scenario research to higher speeds. Further research is also recommended to extend the study to various brands of snowmobiles to check the sensitivity of the data to product features such as weight, centre of gravity and suspension design.

Résumé

Dans la reconstruction de collision, les distances de dérapage sont employées souvent comme outil en déterminant les vitesses l'impact et de pré-impact. En reconstruisant un accident motoneige, le 'dérapage-à-arrêt' la distance de motoneige pareillement soit employé pour aider à déterminer la vitesse d'impact, si le taux de décélération de motoneige est connu. Pour quelques scénarios de base, des taux motoneige de décélération peuvent être estimés à partir de la littérature. Cependant, pour des scénarios où le cavalier motoneige est éjecté pendant l'impact, qui est souvent le cas (comme avec des collisions de moto ou de bicyclette), taux marchant de décélération de motoneige inoccupé est prié. Ce taux marchant de décélération pour des motoneiges n'a pas été étudié précédemment à notre connaissance. Dans des collisions de motocyclette ou bicyclette, le véhicule tombera et un coefficient de frottement coulissant peut être employé. Cependant, une volonté motoneige inoccupée continuent de glisser tout droit si son cavalier est éjecté. Dans ces cas-ci, la suspension motoneige serait prévue au 'déchargent' le poids sur la ceinture de haut-traction qui traîne contre la neige, laissant plus de poids sur l'avant de bas-frottement skie. Dans cette première étude en utilisant un sujet d'expérience de phase, la décélération d'une motoneige mobile a été mesurée quand l'occupant était soudainement 'jeté' du véhicule et la motoneige a été permis de marcher à un arrêt. Des mesures de sécurité ont été prises de s'assurer que les essais pourraient être effectués sans risque. Commençant des vitesses de jusqu'à 40 km/h ont été examinées, sur la neige fraîche de poudre et sur les voies motoneige précédentes. Des courses de commande sans l'éjection d'occupant ont été également conduites aux vitesses de jusqu'à 90 km/h, permettant au motoneige de marcher à un arrêt (simulant un cavalier sans connaissance ou assommé). Pour le 'essais d'occupant éjecté les', la décélération marchante motoneige moyenne étaient 0.24 g, avec 3 des 4 essais étant 0.19 g (0.19 g mn. à 0.39 maximum de g ; 1 'g' = 9.81 m/s²). Essais pour de 'occupant sans connaissance les', la décélération marchante motoneige moyenne étaient beaucoup inférieurs dans la poudre fraîche (0.21 avg de g., gamme de 0.14 g à 0.27 g) que sur les voies préexistantes (0.32 avg de g., gamme de 0.22 g à 0.37 g, avec 3 des 4 essais étant entre 0.34 g et 0.37 g). Quand les résultats ont été classés par catégorie par les vitesses d'essai, d'autres tendances ont émergé. En particulier, la décélération marchante a augmenté de manière significative avec la vitesse accrue (0.19 avg de g. à 26-33 km/h [SD = 0.00 g], 0.25 avg de g. à 40-60 km/h [SD = 0.10 g], 0.35 avg de g. à 90 km/h [SD = 0.01 g]). Les résultats de cette première étude de recherches par ceci sont rendus disponibles aux communautés de reconstruction de secteur public et privé pour aider à analyser des accidents motoneige. Davantage de recherche est recommandée pour recueillir des données additionnelles et pour prolonger la recherche de scénario éjectée par 'à des vitesses plus élevées. Davantage de recherche est également recommandée pour prolonger l'étude à de diverses marques des motoneiges pour vérifier la sensibilité des données aux caractéristiques du produit telles que le poids, le centre de la gravité et la conception de suspension.

INTRODUCTION

In collision reconstruction, skid distances are considered a reliable tool in helping to determine the pre-impact speed of a vehicle. When conducting a collision reconstruction involving snowmobiles, the 'skid-to-stop' distance or slide-to-stop distance of the snowmobile can similarly be used to help determine the pre-impact speed. In order to use the stopping distance

of a vehicle in a collision to accurately determine speeds, one must first know the appropriate drag factor (or range of values) to use for that skid or deceleration. If an unrealistically high drag factor is used, the calculated speed will be too high. If an unrealistically low drag factor is used, the calculated speed will be too low¹. For this reason, Police reconstruction officers generally use the lowest end of the published range of drag factor values for a given situation when determining speeds, in order to be conservative and establish a minimum speed estimate. For example, if a passenger vehicle applies emergency braking and skids for 30 m to a stop on a dry asphalt 60 km/h posted speed limit road (without impacting anything), the assumption of a 0.9 g deceleration² will yield a speed of 83 km/h, whereas an assumption of a 0.7 g deceleration will yield a speed of 73 km/h.

For collisions involving snowmobiles, typical deceleration rates for emergency brake application have been published in the literature, as will be discussed. However, for scenarios where the snowmobile rider is ejected from the snowmobile, the brakes are no longer being applied to the unoccupied snowmobile. The snowmobile is essentially coasting along, typically with some engine drag, unless an engine 'kill-switch' tether is available on the snowmobile and is used by the rider. Based on our review of the literature, the deceleration rate for a coasting, unoccupied snowmobile has not been previously documented. The use of an 'emergency braking' drag factor to calculate the rider's speed in such a scenario could result in a drastic over-estimate.

When investigating motorcycle or bicycle collisions, one can simply assume a 'scraping-metal-on-asphalt' drag factor once the rider has been ejected and the motorcycle or bicycle is sliding on its side against the road surface. Drag factor values for sliding unoccupied motorcycles and bicycles have been thoroughly studied in the literature and are beyond the scope of this paper. In a snowmobile collision, however, the unoccupied snowmobile can continue gliding upright on its skis after its rider has been ejected.

To complicate matters further, the deceleration rate of an unoccupied snowmobile cannot simply be estimated from known friction values for snow because a snowmobile has two opposing friction elements in its fundamental design: the low-friction front skis, and the high-traction belt that is normally used to drive the snowmobile forward or apply the braking force. The snowmobile suspension, which varies from model to model, dynamically distributes the mass of the snowmobile and rider between these two elements. In the event of a rider ejection, one would expect that the reduction of mass on the seat would 'unload' the suspension of the high-traction belt, leaving more of the vehicle mass distributed on the low-friction front skis.

Due to the lack of data in these areas, we conducted an initial study to measure the deceleration of a moving snowmobile when the occupant was suddenly 'thrown' from the snowmobile at speeds of up to 40 km/h. Control runs with no braking and no occupant ejection were conducted at speeds of 40 to 90 km/h.

¹ The calculated speed is proportional to the square root of the drag factor.

² Where 1 'g' is the acceleration due to gravity, 9.81 m/s².

SNOWMOBILE USE AND COLLISIONS IN NORTH AMERICA

Snowmobiling is a popular recreational winter activity in Canada and the United States. There are over 360,000 km of designated snowmobile trails in North America, with over 43,000 km of those trails located in Ontario [1,2]. In 2008, over 50,500 snowmobiles were sold in Canada [3] and over 79,500 snowmobiles were sold in the United States [2]. Snowmobile sales in all other countries of the world accounted for only 33,000 additional units in 2008 [2].

In Canada, there are over 708,000 registered snowmobiles, 43% of which are in Ontario. In the United States, there are 1.62 million registered snowmobiles, 50% of which are in Michigan, Minnesota, and Wisconsin [2]. The average snowmobile rider travels approximately 1600 km per year by snowmobile [2].

Modern recreational snowmobiles are high performance vehicles with masses ranging from 180 to 270 kg, engine sizes of up to 1000 cc, and top speeds on some models above 140 km/h [1].

Unfortunately, snowmobile collisions are common and result in a high incidence of serious injuries and fatalities [1]. During a 17-year study period from 1988 to 2004, over 11,000 snowmobile collisions occurred in Ontario alone, resulting in 548 fatalities and 7972 injuries, with an estimated societal cost of over 3 billion dollars [1]. A review of Elzohairy's data shows that at least 65% of those fatalities occurred during nighttime conditions [1]. The annual number of snowmobile fatalities in Ontario remained relatively consistent over that time period, ranging from a high of 42 fatalities in 1997 to a low of 24 fatalities in 2000 [1]. In 2004, the fatality rate and injury rate in Ontario per registered snowmobile were approximately 1 in 10,000 and 1 in 1000, respectively, resulting in an estimated societal cost of 450 million dollars [1].

In the United States, the incidence of snowmobile collisions and injuries is much worse. In 1995, there were over 16,200 snowmobile-related injuries in the United States among less than 1.3 million registered snowmobiles [4]. These data correspond to a yearly injury rate of more than 1 in 80, as compared to approximately 1 in 1000 in Ontario.

According to Elzohairy's data, in approximately 90% of rider fatality cases, the rider was ejected from the snowmobile [1]. Furthermore, falling off of the snowmobile is among the most common mechanisms for injury [4]. As such, the available data indicate a clear need for deceleration values for unoccupied moving snowmobiles.

REVIEW OF PUBLISHED SNOWMOBILE DECELERATION DATA

There is a limited amount of research in the history of collision reconstruction literature regarding deceleration rates for snowmobiles [5].

In Michigan, the County of Crawford enacted a regulation in 1970 governing the use of snowmobiles, stating that snowmobiles in operation must be capable of producing a braking deceleration of "14 ft/s (4.27 m/s) on level ground at 20 mph (32 km/h)" [6]. This minimum performance regulation presumably refers to a deceleration of 14 ft/s each second (14 ft/s²), which is 4.27 m/s² or 0.44 g. That is, in the County of Crawford, a fully braking snowmobile

must be capable of decelerating at 0.44 g to be considered in 'proper working condition'. The regulation is still in effect in that County.

In 1986, the snowmobile industry produced a set of voluntary standards for recreational snowmobile product certification, entitled "Safety Standards for Snowmobile Product Certification - SSCC/10" [7,8]. The standard states that a snowmobile travelling at 32.2 km/h must be capable of braking to a stop in less than 12.2 m with a rider of at least 77 kg when travelling on packed snow or a uniform grassy surface.³ This minimum performance regulation corresponds to a deceleration of 0.335 g. Again, this deceleration value is applicable to full brake application.

Hermance [7] reported general deceleration ranges of 0.50 to 0.60 g for full snowmobile braking from 48 km/h on 15 cm of powder snow on top of a 60 cm packed snow base. At higher starting speeds, the full braking deceleration increased to 0.60 to 0.75 g for 64 km/h, 0.65 to 0.82 g for 80 km/h, and 0.75 to 0.82 g for 96 km/h. These tested values would all satisfy the minimum performance requirements cited above. Hermance also found that the results did not change significantly for a 60 kg rider vs. a 135 kg rider.

Snowmobile testing conducted in the winter of 1994/1995 by Cst. Stevenson of the RCMP in Nipawin, Saskatchewan (presented in Appendix F of reference 7) reported full braking deceleration values for a variety of road surfaces. When reviewed as a whole, the data indicated decelerations in the range of: 0.22 to 0.27 g for smooth ice-covered gravel at 64 km/h; 0.39 to 0.41 g for packed snow on top of ice-covered gravel at 49 to 56 km/h; 0.38 to 0.46 g for packed snow on a road at 46 to 88 km/h; 0.40 to 0.47 g for 10 to 20 cm of fresh powder at 45 to 57 km/h; 0.42 to 0.50 g for 10 to 20 cm of fresh powder at 72 to 81 km/h; and 0.52 to 0.56 g for 30 cm of fresh powder at 62 km/h. These values were lower than those obtained above by Hermance [7] for similar ground conditions and speeds, but would still satisfy the SSCC/10 minimum industry standard of 0.335 g, except for the smooth ice condition).

More recently, SAE J45 (2003) [9] describes a standard practice for testing the full braking deceleration of a recreational snowmobile on artificial turf with no snow. While this test method is intended to provide repeatable results that can be used to compare different snowmobile models on a 'head-to-head' basis, the test method does not represent drag factor values for snow trail conditions or for rider ejections. Furthermore, this document is a standardized test method, not a performance requirement.

A snowmobile rider training course in Vermont [10] listed typical braking distances for snowmobiles at various speeds from 24 to 96 km/h, with full brake application. The source of the data was not listed. The course overview stated that snowmobile drag factors are higher (i.e. more effective braking) in deep powdery snow, and lower (i.e. less effective braking) on glare ice. Using the listed braking distances, we calculated the implied drag factor at each speed. The implied deceleration was 0.385 g at starting speeds of 48 to 96 km/h, and 0.45 g at starting speeds of 24 km/h. These values were lower than those obtained by Hermance but were consistent with those obtained by the RCMP for packed snow conditions.

We conducted similar calculations using snowmobile 'braking distances' presented on a

³ An alternative braking compliance can be achieved if the traction belt locks upon normal activation of the hand brake.

commercial website [11]. The graphs presented results for full braking tests on two icy surfaces (sheet ice and a hard packed/icy road) with and without track studs. The research was reportedly conducted by Hermance in 1997, which would be after the publication of his textbook, cited as reference 7. The tests were conducted at speeds of 24 to 88 km/h. It is unknown if the results on this commercial website were peer-reviewed. Nevertheless, for interest sake, we calculated the braking decelerations to be (in descending order): 0.385 to 0.405 g for the studded track on the icy road at 40 km/h+ or the sheet ice at 56 km/h+; 0.295 to 0.315 g for the studded track on either surface at 24 km/h or the sheet ice at 40 km/h; 0.20 g for the non-studded track on the icy road at 40 km/h+; 0.15 g for the non-studded track on the icy road at 24 km/h; and lastly, 0.075 g for the non-studded track on sheet ice at all speeds. The high end of these results (studded track on icy road) was comparable to the RCMP results for a layer of packed snow over an icy road. The 0.20 g results (non-studded track on icy road) were similar to the RCMP results for a smooth ice-covered road. The low end of these results (non-studded on sheet ice) was significantly lower than any published research to date and may be unrealistic. A friction coefficient of 0.075 would be comparable to the friction that one would encounter if walking on a skating rink with shoes. Regardless, none of these results are applicable to the case of an ejected rider.

In 2007, Brown [12] reported on snowmobile testing that was conducted by the Ontario Provincial Police North East Region in February 2000 and February 2002 using a mock groomed trail with packed snow. During full braking tests from 41 to 49 km/h, the snowmobile decelerations ranged from 0.39 to 0.43 g. These results were consistent with the RCMP test results for packed snow. Brown reviewed previous Police test results and concluded that for full braking, the drag factor consistently increased with an increase in test speed due to snow build-up in front of the track. Hermance reached a similar conclusion in 1994 [5].

Brown [12] also conducted coast-to-stop tests on the groomed trail, with the rider remaining seated on the snowmobile. Coasting decelerations of 0.21 to 0.24 g were obtained at starting speeds of 43 to 46 km/h. These results were relatively close to the coasting results reported by Hermance [5], who conducted similar coast-to-stop tests on a hard-packed snow surface, with the rider remaining seated on the snowmobile. Hermance obtained decelerations of 0.16 to 0.18 g at a starting speed of 48 km/h, and decelerations of 0.24 to 0.25 g at 64 km/h. However, neither set of results simulated the effect of a rider ejection.

Brown [12] noted that he conducted two successful test runs in which the rider voluntarily jumped off of the moving snowmobile at 31 and 34 km/h. However, those test runs were part of a rollover test in which the snowmobile was intentionally flipped over into a continuous sideways roll using a ramp. No voluntary 'ejection' tests were attempted for the coast-to-stop trials.

TEST METHOD

In this initial study, the deceleration of an unoccupied snowmobile was measured after the rider voluntarily jumped off of the moving snowmobile and it was allowed to coast to a stop in an upright position, with the engine still running.

The following safety measures were taken to ensure that the tests could be conducted safely. The tests were conducted by the authors on March 24, 2008 in a large open field near South

Porcupine, Ontario, (east of Timmins) with a top layer of at least 30 cm of loose powder snow and a base layer of more than 1 m of loosely-packed snow. The deep natural snow coverage in the field provided a soft landing cushion that was more than sufficient for safety purposes, similar to many layers of stacked vault mats. The test rider was equipped with a proper full face guard helmet and numerous layers of clothing for added padding.

The test rider jumped off of the snowmobile when it passed a fixed reference pole in the field. Two preliminary test runs were attempted at speeds of approximately 10 km/h to ensure that the method was safe. This allowed the rider to become accustomed to the jumping motion from an initially seated position and select a comfortable landing position in the soft snow. The landings in the deep snow were comfortable and were not deemed to be hazardous in any way. The rider jumped up and off of the snowmobile to the left, rolling comfortably into a back first landing. The test speeds for the jumps were raised incrementally from 25 km/h up to 40 km/h and four trials were conducted, at which point the set of tests was deemed to be complete. We did not attempt additional jumping trials, or jumps from speeds above 40 km/h in this initial study, due to safety concerns.

These 'ejection' tests were conducted with the unoccupied snowmobile tracking along previous snowmobile tracks through the powder, and were repeated with the snowmobile tracking through fresh powder (i.e. making a new track). The air temperature during the testing period was approximately -5 °C to -8 °C and the weather was clear and sunny. The test site is illustrated in Figure 1 below.

Since the test field was next to a groomed snowmobile trail, we were able to conduct control tests with no 'rider ejection' on both the groomed trail and the fresh powder field. In these tests, the snowmobile was allowed to coast down to a stop from an initial speed of up to 90 km/h, with no braking applied by the rider. In terms of collision reconstruction, this scenario would simulate an unconscious or stunned rider, or a rider coasting from full or near-full speed with no throttle activation for some other reason. The coasting point for these tests began at the same reference line as the 'ejected' tests, when the snowmobile passed a fixed reference pole.

The test snowmobile was a 2007 Ski-Doo Skandic Tundra 300 in excellent condition (Figure 2), obtained from a local rental shop in Timmins. This model of snowmobile had a Rotax 300F engine (269 cc) with a listed dry weight of 172 kg. The test snowmobile did not have an engine 'kill switch' tether strap. The centre-to-centre width of the front plastic skis was 80 cm. The track width was 40.6 cm and the track was not studded. The overall length of the snowmobile from the front of the skis to the rear bumper was 305 cm. The leading edge of the front ski was 17.8 cm high. The front suspension was listed as a single 'A-arm' suspension with motion control shocks and 160 mm of travel. The rear suspension was listed as a SC-136 suspension with a motion control front arm shock and an HPG rear arm shock and 331 mm of travel. The test subject for each trial was kept constant (1.85 m tall male, 86 kg).



Figure 1: View of the test site area near South Porcupine, Ontario. Note the groomed trail in the foreground and the fresh powder snow in the field in the background.



Figure 2: View of the test snowmobile (2007 Ski-Doo Skandic Tundra 300).

All coast-to-stop distances were measured with a 32 cm diameter rolling wheel, which was rolled slowly on the hard-packed groomed trail and double checked to ensure that no slippage occurred during the measurements. In terms of speeds, it has been reported that snowmobile speedometers may not be accurate for research purposes due to the possibility of the track slipping against the ground and moving faster than the actual vehicle speed [1]. This particular snowmobile was not equipped with a speedometer or a tachometer regardless. Starting speeds were measured using stopwatch timings over a pre-marked 10 m distance. This 10 m distance ended 13 m prior to the 'jump point' (or the throttle release point for the non-ejected trials).

Given the nature of the tests, we did not have the option of using a radar gun during this initial study due to safety concerns. For our radar gun reading to be accurate, the measurement would have to be taken from a standing position in chest-high snow, far downfield or upfield of the test site, within 10° of the path of the high speed snowmobile. More importantly, such a location would place the measurer in a concealed position within the path of other snowmobilers in the area who were uninformed of our presence. For the purpose of this initial study, the use of stopwatch timings was therefore deemed to be preferable. For a full research study, the use of more precise speed measurement techniques would be recommended.

To minimize the error associated with the stopwatch timings, the timings were conducted by the same person throughout the tests. Initial trial runs were conducted to assist in anticipating the beginning and ending of the timed interval. It was expected that any remaining reaction time error at the beginning of the timed interval would be balanced by a similar reaction time error at the end of the timed interval. For the most part, consistent results were obtained for identical throttle settings and we were able to obtain known starting speeds within reasonable accuracy, with one or two exceptions discussed below.

RESULTS AND DISCUSSION

The test results from this initial research study are presented in Table 1. Despite the inherent variability in drag coefficient testing of a snow covered surface, consistent results were obtained with the exception of trial run 4, and to a lesser extent, trial run 8. The average coasting deceleration for all test runs combined was 0.26 g with a standard deviation (SD) of 0.09 g. The deceleration for all tests ranged from a minimum of 0.14 g to a maximum of 0.39 g. In Table 2, the results are categorized according to the various test conditions.

For the 'ejected occupant' test runs, the average snowmobile coasting deceleration was 0.24 g, with 3 of the 4 test runs yielding consistent decelerations of 0.19 g. The coast-to-stop distances for the unoccupied snowmobile in this set of tests ranged from 14 to 22 m. The fourth trial ('test run 4') was an outlier, yielding a deceleration value (0.39 g) that was more than twice the other 'ejected occupant' decelerations, and higher than all of the other test groupings. It is believed that this outlier was likely due to some combination of stopwatch timing error and early release of the throttle prior to jumping, causing the actual starting speed to be closer to 30 km/h, which would be more consistent with the first three test runs. A stopwatch timing error of 0.2 s followed by an early release of the throttle by 3 m would be sufficient to account for this error. Additional testing could be conducted to verify this theory.

Test Run	Coasting Condition	Starting Speed (km/h)	Coasting Distance (m)	Deceleration (m/s ²)	Deceleration (g)
1	rider off, in pre-made tracks	26	14	1.8	0.19
2	rider off, in pre-made tracks	33	22	1.9	0.19
3	rider off, fresh powder snow	30	18.5	1.9	0.19
4	rider off, fresh powder snow	40	16	3.9	0.39
5	rider on, on groomed trail	90	91.6	3.4	0.35
6	rider on, on groomed trail	90	87.1	3.6	0.37
7	rider on, on groomed trail	90	92.6	3.4	0.34
8	rider on, fresh powder snow	40	45	1.4	0.14
9	rider on, fresh powder snow	60	52	2.7	0.27
10	rider on, fresh powder snow	60	66	2.1	0.21
11	rider on, in pre-made tracks	60	67	2.1	0.21

Table 1: Test Results for all Trials

Test Condition Category	Deceleration Range (g)	Average Deceleration (g)	Standard Deviation	Number of tests
Rider off, in pre-made tracks	0.19	0.19	0.00	2
Rider off, in fresh powder	0.19 to 0.39	0.29	0.14	2
Rider on, on groomed trail	0.34 to 0.37	0.35	0.01	3
Rider on, in fresh powder OR pre-made tracks in powder	0.14 to 0.27	0.21	0.05	4
<u>By rider ejection</u>				
Rider ejected	0.19 to 0.39	0.24	0.10	4
Rider not ejected	0.14 to 0.37	0.27	0.09	7
<u>By ground condition</u>				
In fresh powder	0.14 to 0.39	0.24	0.10	5
In pre-made tracks in powder	0.19 to 0.21	0.20	0.01	3
On groomed trail	0.34 to 0.37	0.35	0.01	3
<u>By speed</u>				
26 - 33 km/h	0.19	0.19	0.00	3
40 - 60 km/h	0.14 to 0.39	0.25	0.10	5
90 km/h	0.34 to 0.37	0.35	0.01	3

Table 2: Coasting Deceleration Results Categorized by Test Condition

For the 'unconscious occupant' test runs (i.e. non-ejected rider), the average snowmobile

coasting deceleration was 0.27 g [SD = 0.09 g]. This deceleration was marginally higher than the 0.24 g average deceleration for the 'ejected occupant' tests, although the tests were conducted at different speed ranges. If one considers the strong bias of the single outlier in test run 4, the difference between the two sets of test data is greater. Excluding this outlier, the average deceleration rate was 0.19 g for unoccupied coasting vs. 0.27 g for occupied coasting. This difference is further emphasized if one considers that test run 8 was, to some extent, an outlier as well. It is believed that the actual starting speed for test run 8 may have been closer to 50 km/h, likely due to stopwatch timing error. Nevertheless, we have included test run 8 within our analysis of the above data.

Our average coasting deceleration for an occupied snowmobile at 40 to 60 km/h (0.21 g) was consistent with the results of Brown [12], who reported values of 0.21 to 0.24 g in that speed range, and was midway between the two sets of results in Hermance [5] (which were 0.24 to 0.25 g at 64 km/h, and 0.16 to 0.18 g at 48 km/h).

A distinct trend was observed when the results were categorized according to initial speed (see last grouping in Table 2). The average coasting deceleration of the snowmobile increased as the speed of the test increased, regardless of all other conditions. Despite the various test conditions in each of these speed groupings, the standard deviations were lowest when the data was grouped in this manner, even when including the outliers. At 26 to 33 km/h, the average coasting deceleration for all tested conditions was 0.19 g [SD = 0.00 g]; at 40 to 60 km/h, the average coasting deceleration for all tested conditions was 0.25 g [SD = 0.10 g]; and at 90 km/h, the average coasting deceleration was 0.35 g [SD = 0.01 g]. From a collision reconstruction perspective, these standard deviations were relatively small, considering the limited number of test runs in this initial study.

This finding suggests that starting speed at the beginning of a coasting period is closely related to the average drag factor over that coasting period, and may be the best indicator of whether or not an appropriate drag factor was selected. As such, the findings of both Hermance and Brown regarding increased snowmobile deceleration at increased starting speeds can be extended to coasting scenarios as well as braking scenarios. Therefore, an iterative approach should be used in collision reconstruction to compare the initial drag factor estimate to the resulting speed finding, revising the initial estimate until a solution set is reached.

Regarding the issue of 'ejected' vs. 'non-ejected' coasting decelerations, further testing will be required to isolate the contribution of starting speed from the rider condition before definitive conclusions can be reached on that point. The limited number of test runs and conditions conducted within this initial study does not warrant a detailed statistical analysis. The results do show that a full study of 'ejected' vs. 'non-ejected' occupant scenarios at identical speeds is warranted, since the average deceleration of the unoccupied snowmobile appeared to be relatively low. For now, we recommend that low-end-of-the-range coasting deceleration rates should be considered when reconstructing a snowmobile collision where an ejection occurred.

In the follow-up study, a full range of 'ejected' scenario tests should be conducted at both high and low starting speeds, using appropriate safety measures, since both scenarios are encountered when assessing snowmobile collisions. If the rider is thrown from the snowmobile without a significant impact to the snowmobile, then the starting speed for the 'unoccupied coasting' period will be relatively high. If the rider is thrown from the snowmobile due to a large

impact to the snowmobile, then the speed of the snowmobile at the beginning of the 'unoccupied coasting' period will be relatively low.

The results of this initial research study are hereby being made available to both the public and private sector reconstruction communities to assist in analyzing snowmobile accidents. Further research is recommended to gather additional data and to extend the 'ejected' scenario research to higher speeds and other models of snowmobiles, including studded tracks. Clearly, this initial study was limited to one particular model of snowmobile with one particular type of suspension. Further testing should be conducted on a wide range of snowmobiles brands to check the sensitivity of these results to product features such as weight, centre of gravity, ski construction, number of studs, and suspension design. Testing should also be conducted using snowmobiles with engine 'kill switches' that automatically turn off the engine in the event of a rider ejection.

CONCLUSIONS

In this initial study, the average coasting deceleration for an 'ejected' rider scenario on a particular model of snowmobile, at speeds up to 40 km/h, was found to be 0.24 g. Excluding a single outlier data point that strongly biased the rest of the 'ejected' scenario data, the average deceleration for an unoccupied snowmobile in this speed range was consistently 0.19 g.

The average coasting deceleration for a non-ejected rider scenario on a particular model of snowmobile, at speeds of 40 to 90 km/h, was found to be 0.27 g.

Our test results demonstrated that the finding of both Hermance and Brown regarding increased snowmobile deceleration at increased speed can be extended beyond braking scenarios to coasting scenarios as well. When our results were categorized by test speed, the coasting deceleration rate increased with increasing speed, regardless of all other test conditions.

Despite the limited number of test runs in this initial study, the results indicate that a full research study of 'ejected' vs. 'non-ejected' occupant scenarios is warranted. In particular, testing of 'ejected' occupant scenarios is required for starting speeds in the range of 60 to 90+ km/h, using appropriate safety strategies.

When reconstructing snowmobile collisions involving ejections, one should consider using low-end coasting deceleration values. The use of high-end published values for coasting deceleration may lead to speed over-estimates. Certainly, the use of a 'full brake application' drag factor would be inappropriate for collisions where the snowmobile coasts to rest, since the deceleration values for braking snowmobiles are much higher than those for coasting snowmobiles under all conditions.

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