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Evaluation of Aviation Rumble Strips

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16. Abstract

This interim report provides information about one potential strategy to mitigate the risk of incursions: rumble strips tailored to aviation. Aviation rumble strips may provide advance warning when entering an active runway or taxiway entrance that has published “hot spots.”

A test bed of raised and sawcut rumble strips was installed, and quantitative and qualitative assessments were performed with a Cirrus SR20, Cessna 152, Cessna 172, Piper PA-28 Warrior, and Piper PA-34 Seneca at varying taxiing speeds. This test fleet represents approximately 66% of aircraft operating at general aviation (GA) airports. This interim report provides tables and graphics that summarize both qualitative and quantitative data. The sawcut and raised rumble strips were clearly discernable in the three-axis acceleration data for all GA aircraft at all speeds. The work is ongoing, but discussion of these preliminary results by the aviation community will be valuable to shape future research and testing.

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LIST OF ACRONYMS

ATC	Air traffic control
FAA	Federal Aviation Administration
GA	General Aviation
PCC	Portland cement concrete

EXECUTIVE SUMMARY

Runway safety is a top priority of the Federal Aviation Administration (FAA). A significant threat to runway safety is runway incursions, i.e., unauthorized entry onto a runway. In 2013, 1241 runway incursions were reported to the FAA, a 30% increase since 2009. While the majority of these incursions did not result in a collision, they still presented the potential for serious damage and injury. Reducing runway incursions is important to increase runway safety.

This report provides information about one potential strategy to mitigate the risk of incursions: rumble strips tailored to aviation. Aviation rumble strips may provide advance warning when entering an active runway or taxiway entrance that has published "hot spots." Rumble strips installed on roadways have successfully reduced targeted crashes by as much as 45%. On roadways, rumble strips provide an audible and tactile warning when crossing the centerline (centerline rumble stripes), crossing onto the shoulder (edgeline rumble stripes), or approaching a work zone, railroad crossing, or intersection (transverse rumble strips). Given these highway benefits and the low cost of rumble strips, the focus of this research was to provide a preliminary assessment during non-winter conditions of rumble strips for general aviation (GA) aircraft in a controlled field study. A test bed of raised and sawcut rumble strips was installed, and quantitative and qualitative assessments were performed with a Cirrus SR20, Cessna 152, Cessna 172, Piper PA-28 Warrior, and Piper PA-34 Seneca at varying taxiing speeds. This test fleet represents approximately 66% of aircraft operating at GA airports.

This report provides tables and graphics that summarize both qualitative and quantitative data. The sawcut and raised rumble strips were clearly discernable in the three-axis acceleration data for all GA aircraft at all speeds. The work is ongoing, but discussion of these preliminary results by the aviation community will be valuable to shape future research and testing.

1. INTRODUCTION.

Aviation safety, particularly runway safety, is a top priority for all aviation stakeholders. Runway incursions are a significant threat to runway safety. The Federal Aviation Administration (FAA) defines a runway incursion as, "any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and takeoff of aircraft." [1] Runway incursions must be reported at all airports having air traffic control (ATC) towers. In 2013, 1241 runway incursions were reported to FAA [2]. This is an 8% increase since 2012 and a 30% increase since 2009 [2]. Moreover, the number of reported incursions may be understating the potential risk. Because the majority of general aviation (GA) airports do not have an ATC tower, many runway incursions at GA airports may go unreported, and as a result, the incidence and severity of the problem may not be fully recognized.

Runway incursions can occur due to an operational incident, a vehicle/pedestrian deviation, or a pilot deviation. An operational incident occurs as a result of an ATC action, such as when aircraft spacing does not meet the minimum required separation between aircraft. A vehicle/pedestrian deviation occurs when a pedestrian or ground vehicle enters the airport movement area without ATC authorization. A pilot deviation occurs when the action of a pilot violates a Federal Regulation, such as when a pilot crosses a runway without permission. Approximately 80% of incursions are the result of pilot deviations (63%) and vehicle/pedestrian deviations (18%), so strategies to raise situational awareness regarding upcoming taxiway entrances onto live runways may be appropriate and effective [3].

The use of aviation rumble strips as a method to raise situational awareness and warn of the upcoming danger is one strategy under evaluation. Placing rumble strips tailored to aviation at the beginning of the enhanced taxiway centerline marking on an entrance taxiway may be an effective way to provide a tactile warning of the approaching runway and runway threshold. Highway rumble strips have been successfully deployed in roadway applications and have significantly reduced targeted crashes by up to 45% [4 through 6]. On roadways, rumble strips provide an audible and tactile warning of the dangers associated with crossing the centerline (centerline rumble stripes), crossing onto the shoulder (edge line rumble stripes), or approaching a work zone, railroad crossing, or intersection (transverse rumble strips). Given the documented success of highway rumble strips in the roadway environment, the low cost, and the potentially significant benefits, the purpose of this research was to provide preliminary evaluation of aviation rumble strips in a controlled field test. The primary application targeted in this research was GA airports, during non-winter conditions, although rumble strips may be appropriate at GA airports, more research is necessary to determine the appropriateness at larger airports that typically serve larger aircraft under all-weather conditions.

In addition to potential use along enhanced taxiway centerline markings, a second potential application of aviation rumble strips is to warn of airport hot spots at confusing taxiway/taxiway intersections. The FAA defines a hot spot as, "a location on an airport movement area with a history of potential risk of collision or runway incursion, and where heightened attention by pilots and drivers is necessary." [1]

Sections 2 through 7 summarize past initiatives using rumble strips at airports, describe ongoing activities to update that research, and summarize rumble strip data collected in 2014. It is anticipated that this report will provide a basis for discussion in the aviation community regarding the viability of rumble strips.

2. BACKGROUND.

Aviation rumble strips were proposed in 1980 and evaluated for potential use by the FAA [7]. Plywood strips (1/2 in. high, 6 in. wide, 8 ft long) were used to create a raised rumble strip test bed (figure 1), and a qualitative assessment regarding whether the rumble strips were noticeable was made for four aircraft at speeds from 5 to 25 mph. The 8-foot length of the rumble strips affected the nose landing gear, but was not wide enough to affect the main landing gear. Results from the 1980 study are summarized in table 1. The study concluded that the rumble strips would be of limited use since they were effective for only one aircraft at all speeds tested.

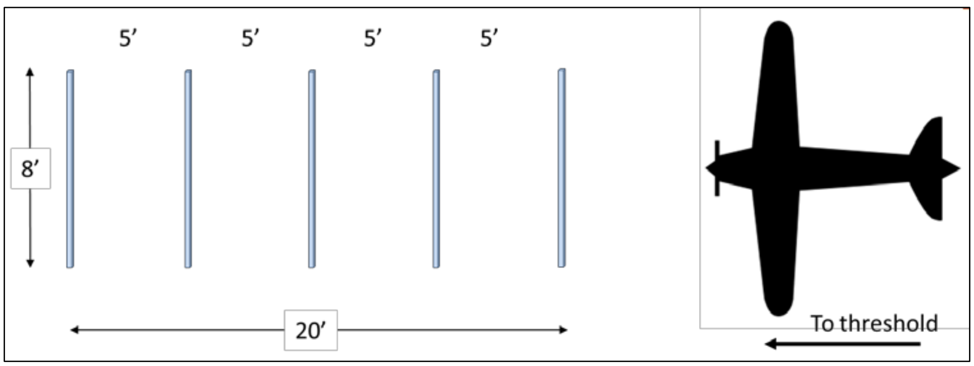


Figure 1. Experimental Raised Rumble Strip Configuration (6″ wide by 0.5″ high) Evaluated by FAA in 1980 [7]

Table 1. Summary of 1980 FAA Rumble Strip Qualitative Evaluation [7]

Aircraft	Empty Weight (lb)	Max Weight (lb)	Are Rumble Strips Noticeable in Cockpit?			
			10 kt	15 kt	20 kt	25kt
Cessna 172	1,641	2,558	-	YES	YES	YES
AERO Commander 680E	4,740	6,750	-	-	-	-
Gulfstream 159	21,900	35,100	-	YES	YES	YES
Convair 580	30,275	58,140	YES	YES	YES	YES

Rumble strips were also proposed in Embry-Riddle's winning entry for Runway Safety/Runway Incursions Challenge Category of the FAA 2011 Design Competition for Universities. The proposal suggested that aviation rumble strips on taxiways near taxiway entrances to runways would send a tactile signal to pilots alerting them that they are entering a potentially dangerous area (e.g., a runway), which may raise situational awareness and potentially reduce the likelihood of a runway incursion [8].

This research request was developed as part of the 2013 Runway Incursion Team's Mitigation Plan, which was drafted following an analysis of airport accident and incident data from January 2001to December 2011. This analysis summarized data from various aviation databases in an effort to identify top airport risk areas for airport safety and where the FAA Office of Airport Safety and Standards should focus its future research initiatives. Runway incursions were identified as a top airport risk area. Therefore, it was recommended that the FAA Airport Technology Research and Development Branch initiate a research project to re-examine potential benefits of using aviation rumble strips as an effective means for reducing runway incursions for all aircraft and vehicle sizes. The FAA is conducting this research with Purdue University and Ohio State University through the Partnership to Enhance General Aviation Safety Accessibility and Sustainability (PEGASAS) Center of Excellence.

2.1 RUMBLE STRIP CONSTRUCTION.

Rumble strips have been successfully used in many roadway applications. Roadway rumble strips may be milled, rolled, formed or raised [6]. These rumble strips differ in installation method, shape, and size, which affects the resulting vibration and noise level [6].

2.2 MILLED, ROLLED, AND RAISED RUMBLE STRIP CHARACTERISTICS.

Milled rumble strips are easily installed on new or existing asphalt and Portland cement concrete (PCC) surfaces and are preferred by most transportation agencies. Milled rumble strips are made by a milling machine with a rotary cutting head that cuts smooth, uniform, and consistent grooves into the pavement [6 and 9]. Milled rumble strips produce a "great amount of noise and vibration," alerting drivers of a potentially unsafe condition [6]. Common dimensions of milled centerline and shoulder rumble strips are: 16 in. long by 7 in. wide by 0.5 in. to 0.625 in. deep by 12 in. center to center [6 and 9]. The wider and deeper the rumble strips, the more sound and vibration the strips produce because of "tire-drop capabilities." [6] However, tire drop depends on several factors including tire characteristics, speed, and rumble strip spacing [6].

Rolled rumble strips are either rounded or v-shaped grooves pressed into constructed or reconstructed asphalt surfaces [6 and 9]. Rolled rumble strips are less noticeable than milled rumble strips [10 and 11], and their effectiveness may be limited by insufficient compaction and inadequate dimensions [12]. Formed rumble strips are shaped like rolled rumble strips; however, they are installed in PCC surfaces during the finishing process, rather than asphalt surfaces [6, 9, 10, and 11]. Rolled and formed rumble strips are not recommended for use at civil airports because they can only be installed on newly constructed pavement surfaces [6 and 9]. Furthermore, the sound and vibration of rolled and formed rumble strips is typically much less than milled rumble strips [6].

Raised rumble strips are "strips of material that adhere to new or existing pavement surfaces" [6], and may be asphalt, raised pavement markers, or thermoplastic [6 and 13]. Raised rumble strips are typically 2 in. to 12 in. wide, rounded or rectangular, and 1/4 in. to 1/2 in. high [9]. There may be maintenance concerns with raised rumble strips, particularly in regions where snow is prevalent [6].

3. TEST BED AND EXPERIMENTAL EVALUATION PROCEDURE.

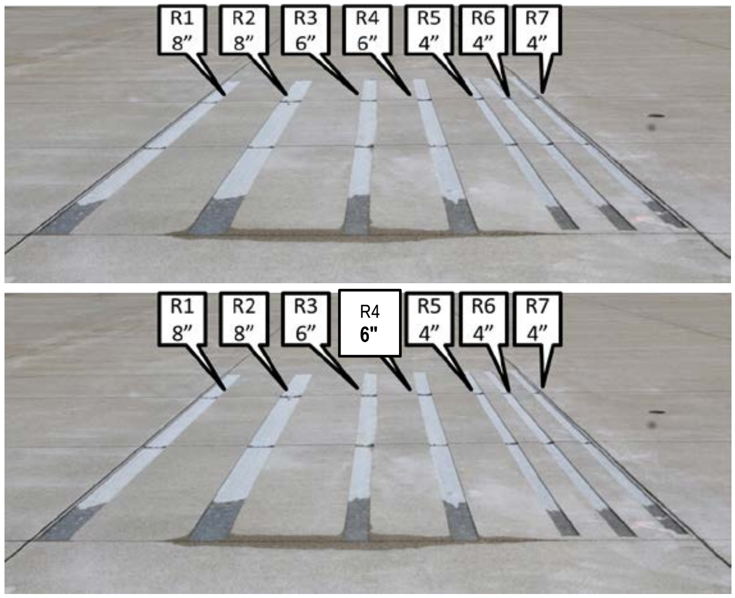
This research constructed a test facility at the Purdue University Airport with both sawcut (figure 2(a) and (c)) and raised rumble strips (figure 2(b) and (d)). The raised rumble strips were constructed first because of their flexibility for empirically assessing alternative spacing in a short time.

The seven rumble strips in the sawcut installation are shown in figure 2(a). R1 and R2 were 8 in. wide, R3 and R4 were 6 in. wide, and R5, R6, and R7 were 4 in. wide. Sawcut rumble strips were used rather than milled rumble strips because the focus of the project was GA airports, and equipment to install sawcut rumble strips was much more readily available than equipment to install milled rumble strips. Milling machines remove a larger area of pavement at a time than sawcutting machines; however, they are larger and more costly. A photograph of a portion of the 6″ wide sawcut R3 rumble strip is shown in figure 2(c) (all dimensions nominal). The center-to-center spacing between installed stripes for both the sawcut and raised rumble strips was 3 ft, 3 ft, 2 ft, 2 ft, 1 ft, 1 ft′ (as shown in figure 2(b)), but the raised rumble strips were all 4 in. wide (figure 2(d)).

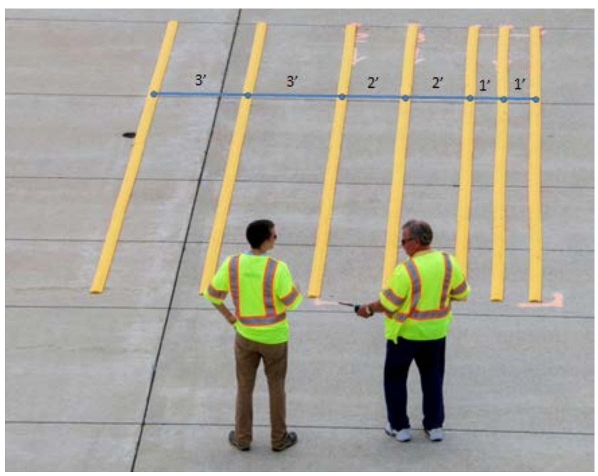
The completed test bed included a 20-ft-wide sawcut rumble strip configuration followed by a 24-ft-wide raised rumble strip configuration (the raised rumble strips came in 6-ft modules). The width was increased relative to the 1980 design to allow all landing gear for most GA aircraft to traverse the rumble strips. The sawcut and raised rumble strips sections were separated, so the residual acceleration from the first section was unable to impact the second section for most GA aircraft.

For each configuration, a variety of aircraft taxied over the rumble strips at varying speeds. For each test run, quantitative assessment was provided using a three-axis accelerometer, which was typically mounted on the seat strut or seat rail. A qualitative rating on a scale from 1 to 5, as described in table 2, was assigned by a researcher riding in the aircraft, and a video was recorded to document the test run. This was a relative scale; a rating of 2 simply means not quite 1 or 3, and a rating of 4 means not quite 3 or 5.

The qualitative rating expands on the “yes” or “no" assessment in the 1980 study. Radio communication between the researcher in the aircraft and the researchers on the ground was recorded on the audio track of the video.



(a) Sawcut Rumble Strip Configuration



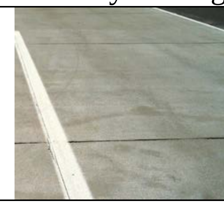
(b) Raised Rumble Strip Configuration

(c) The 6″ Wide Sawcut Rumble Strip

(d) The 4″ Raised Rumble Strip Profile

Figure 2. Rumble Strip Configuration Design

Table 2. Summary of 2014 Rumble Strip Qualitative Evaluation Rating Scale

Numerical Score	Qualitative Description	Roadway Analogy	Illustration of Roadway Analogy
1	Minimal impact	Driving over concrete joints at speed limit.	
2			
3	Appropriate impact, noticeable and perhaps annoying	Driving on longitudinal rumble strips on edge line or centerline on highway at speed limit.	
4			
5	Excessive impact, unpleasant and jarring; may cause concern for damage	Driving over a raised speed bump at speed limit.	

A sample accelerometer plot over 10 seconds is shown in figure 3. This plot has four trace lines, the x, y, and z components of the three-axis accelerometer, and the resultant magnitude (Mag) of all forces. In some cases, the graphs of the x and y components overlap. In figure 3, the response to the sawcut rumble strips begins at approximately 13:54:29, and the response to the raised rumble strip begins between 13:54:30 and 15:54:31. Although all three axes of the accelerometer show some response to the rumble strips, in many cases, the most pronounced response is the vertical (z) component.

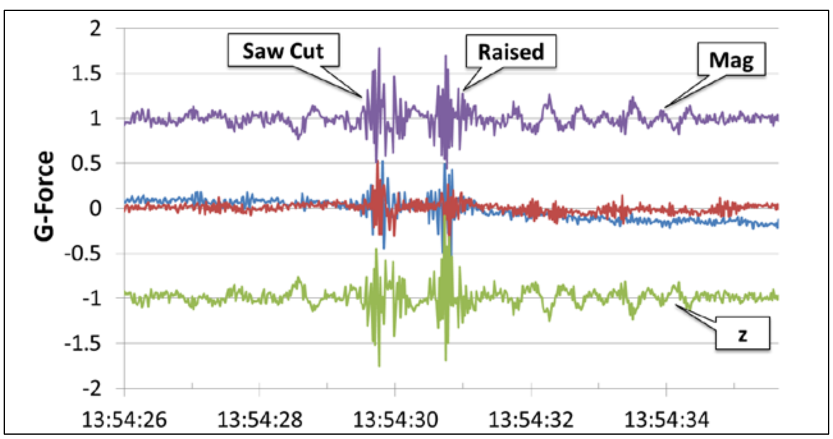


Figure 3. Example Data Collected From Three-Axis Accelerometer
Mounted on Cessna 172 Seat Rail

Table 3 provides the qualitative ratings and additional information about the aircraft tested. A score of 2 or above is considered analogous to a "yes" in the 1980 study as documented in table 1. Data for the Cirrus aircraft, which are university owned, was limited to 15 mph or below for compliance with university taxiing speed policies.

Table 3. Sample Qualitative Ratings for Aircraft Over Raised (R) and Sawcut (S) Rumble Strips

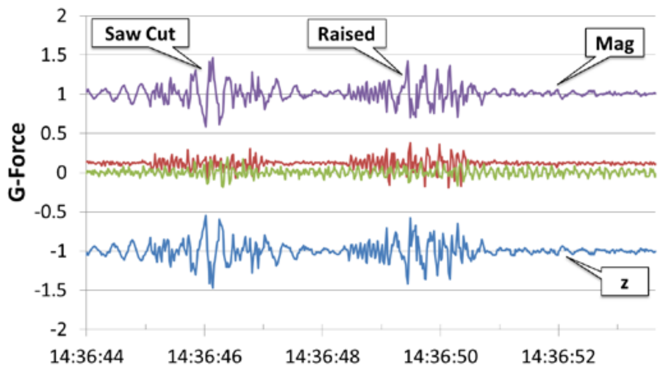
Aircraft	Suspension Type (Nose)	Suspension Type (Main)	Empty Weight (lb)	Max Weight (lb)	Type	5 kt	10 kt	15 kt	20 kt
Cirrus CR20	Spring Steel	Spring Steel	2128	3050	R	3	3	4	*
					S	3	3	3	*
Cessna 152	Shock Strut	Spring Steel	1151	1670	R	2	3	3	2
					S	2	3	3	2
Cessna 172	Shock Strut	Spring Steel	1691	2450	R	2	2	3	2
					S	2	2	2	2
Piper PA-28 Warrior	Shock Strut	Shock Strut	1590	2500	R	1	1.5	1	1
					S	1	1	1	1
Piper PA-34 Seneca	Shock Strut	Shock Strut	2623	4000	R	2	2	3	2.5
					S	2	2	2	2.5

*Policy limits taxi speed for university aircraft

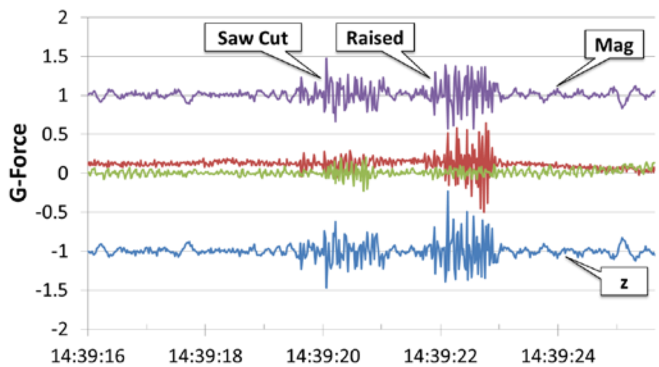
4. DATA SET.

Data were collected for six aircraft: the Cirrus SR20, Cessna 152, Cessna 172, Piper PA-28 Warrior, and Piper PA-34 Seneca. Sample acceleration plots for each aircraft at a variety of speeds are shown in appendix A. These aircraft represent the fixed wing piston aircraft that comprise approximately 66% of aircraft at GA airports (59% single engine, 7% twin engine) [14]. The Cirrus, Cessna, and Warrior are single-engine aircraft, the Seneca is a twin-engine piston engine aircraft. Appendix A contains a detailed set of acceleration measurements for the six types of aircraft that evaluated and traversed the rumble strips. Also included are acceleration graphs for F250 pick-up truck traversing road speed bumps, centerline rumble strips, and edge line rumble strips.

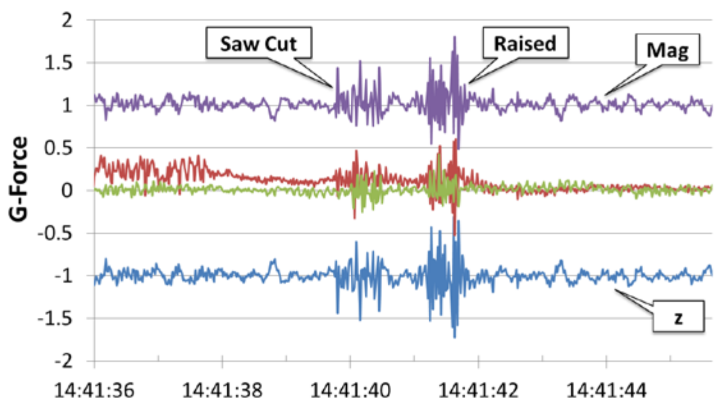
Figure 4(a) through (c) shows acceleration plots when the Cirrus traverses both the sawcut and raised rumble configurations at 5, 10, and 15 kt, respectively. As the speed increases, the acceleration signatures become more compressed, and there is some increase in amplitude. The amplitude of the acceleration is greater for the raised rumble strips not only in the z direction, but also in the x and y directions, resulting in a higher rating for the raised configuration.



(a) Cirrus SR20 at 5 kt
(rating for sawcut = 3, raised = 3)



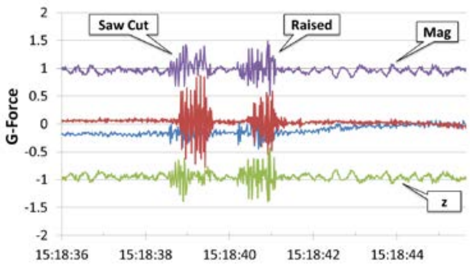
(b) Cirrus SR20 at 10 kt
(rating for sawcut = 3, raised = 3)



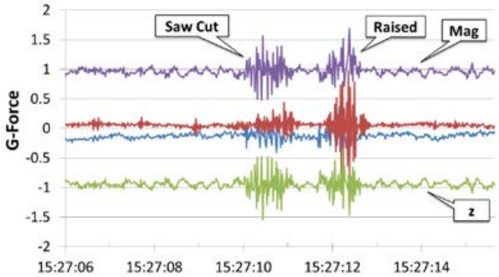
(c) Cirrus SR20 at 15 kt
(rating for sawcut = 3, raised = 4)

Figure 4. Acceleration Plots of Cirrus SR20 Over Sawcut and Raised Rumble Strips

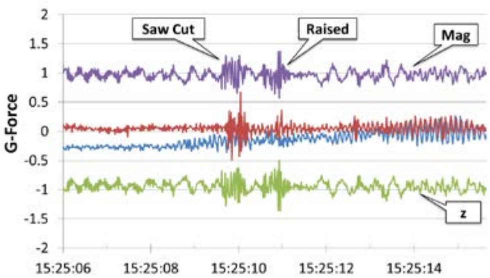
Selected acceleration plots for Cessna 152 tests at 5, 10, 15, and 20 kt are shown in figure 5(a) through (d). The trials shown were reported to be a 2 or 3 (table 2), with 10 and 15 kt reported to be the most notable qualitatively for both the sawcut and raised rumble strips. Figure 5(e) through (h) shows the acceleration plots for Cessna 172 tests at 5, 10, 15, and 20 kt. All trials were reported to be a 2 or 3 (table 2), with the raised rumble strip having the most notable effect at 15 kt.



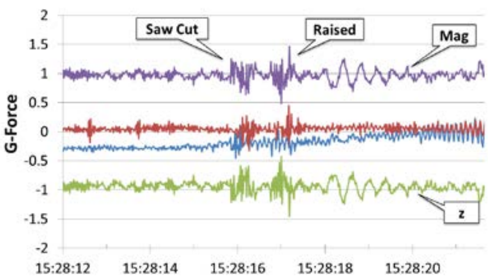
(a) Cessna 152 at 5 kt
(rating for sawcut = 2, raised = 2)



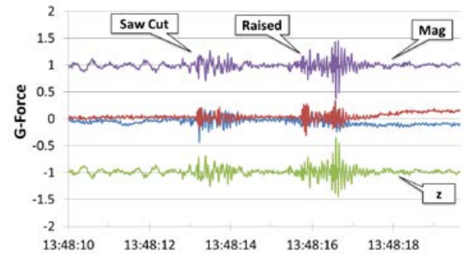
(b) Cessna 152 at 10 kt
(rating for sawcut = 3, raised = 3)



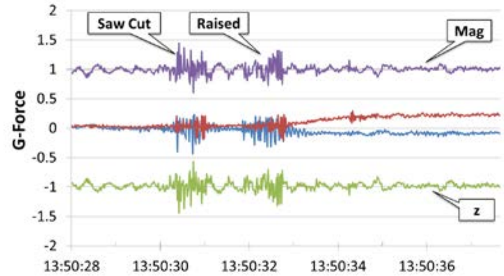
(c) Cessna 152 at 15 kt
(rating for sawcut = 3, raised = 3)



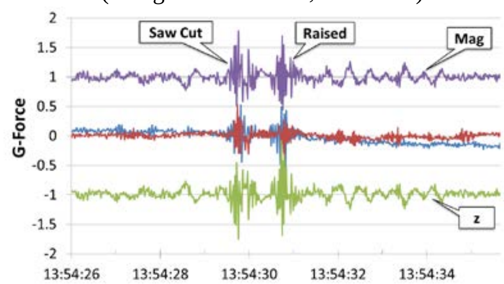
(d) Cessna 152 at 20 kt
(rating for sawcut = 2, raised = 2)



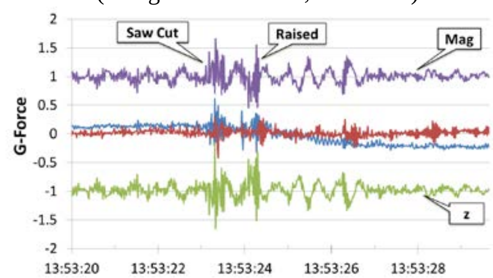
(e) Cessna 172 at 5 kt
(rating for sawcut = 2, raised = 2)



(f) Cessna 172 at 172 at 10 kt
(rating for sawcut = 2, raised = 2)



(g) Cessna 172 at 15 kt
(rating for sawcut = 2, raised = 3)

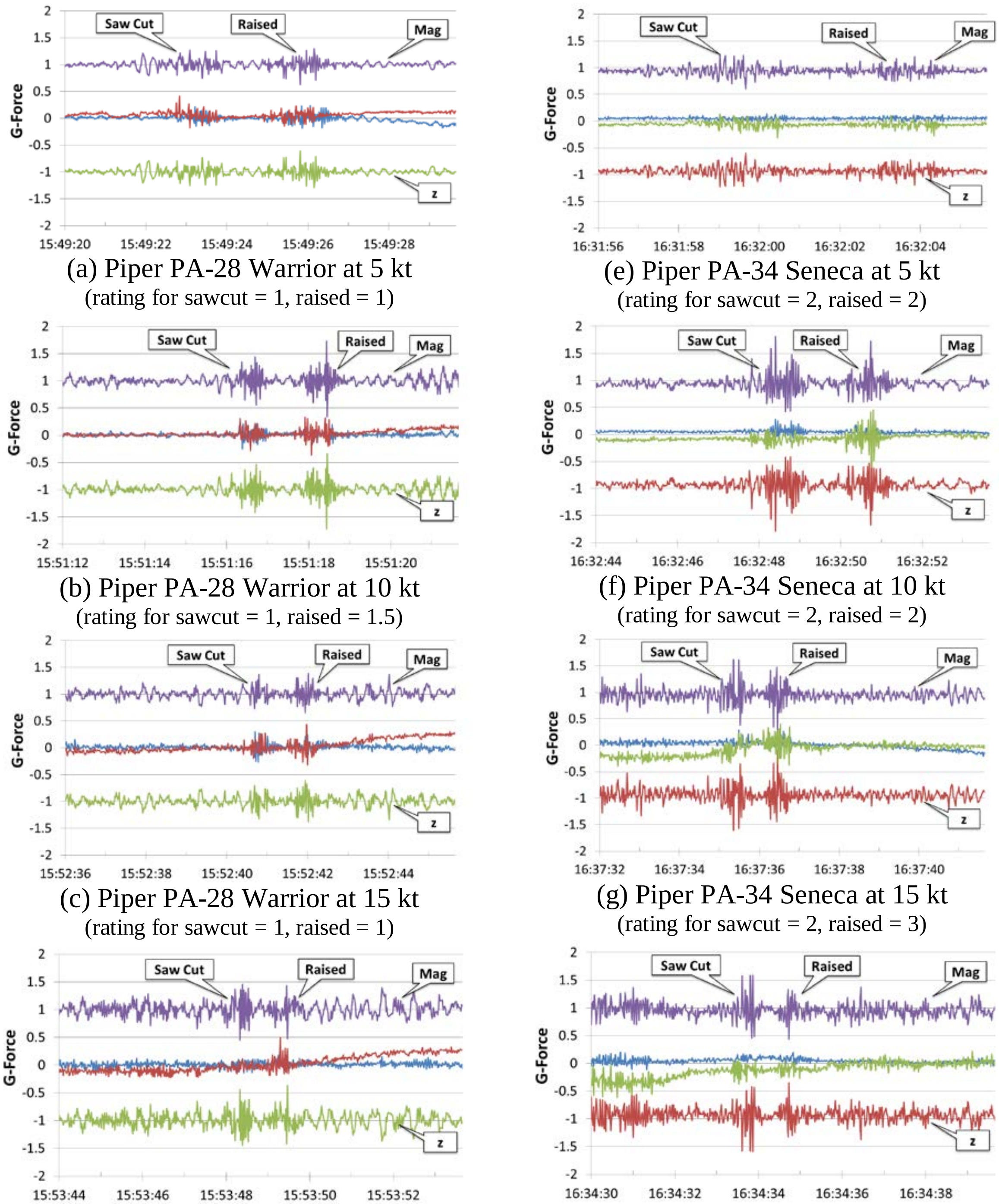


(h) Cessna 172 at 20 kt
(rating for sawcut = 2, raised = 2)

Figure 5. Acceleration Plots of Cessna Aircraft Over Sawcut and Raised Rumble Strips

Figure 6 contains selected acceleration plots for a Piper PA-28 Warrior (figure 6(a) through (d)) and Piper PA-34 Seneca (figure 6(e) through (h)) at 5, 10, 15, and 20 kt. The Piper PA-24 Warrior had the lowest qualitative rating (all below 2) of all the aircraft studied. The highest rating of 1.5 correlated with a single spike in acceleration in the z direction when traversing the raised rumble strips at 10 kt (figure 6(b)).

The sample plots for the Piper PA-34 Seneca are shown in figure 6(e) through (h) and range from a rating of 2 to 3, with a peak rating of 3 for the raised rumble strip configuration at 15 kt (figure 6(g)). Based on examination of the accelerometer plot, this higher rating may be due to motion in the forward direction rather than in the z direction.



(a) Piper PA-28 Warrior at 5 kt
(rating for sawcut = 1, raised = 1)

(b) Piper PA-28 Warrior at 10 kt
(rating for sawcut = 1, raised = 1.5)

(c) Piper PA-28 Warrior at 15 kt
(rating for sawcut = 1, raised = 1)

(d) Piper PA-28 Warrior at 20 kt
(rating for sawcut = 1, raised = 1)

(e) Piper PA-34 Seneca at 5 kt
(rating for sawcut = 2, raised = 2)

(f) Piper PA-34 Seneca at 10 kt
(rating for sawcut = 2, raised = 2)

(g) Piper PA-34 Seneca at 15 kt
(rating for sawcut = 2, raised = 3)

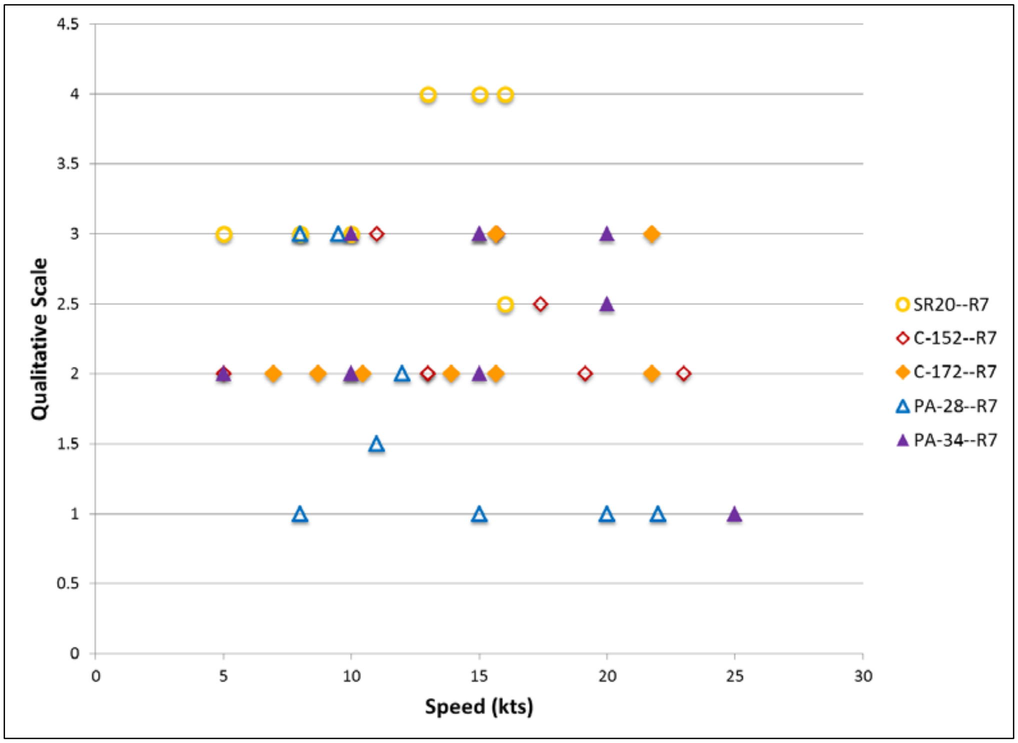
(h) Piper PA-34 Seneca at 20 kt
(rating for sawcut = 2.5, raised = 2.5)

Figure 6. Acceleration Plots of Piper Aircraft Over Sawcut and Raised Rumble Strips

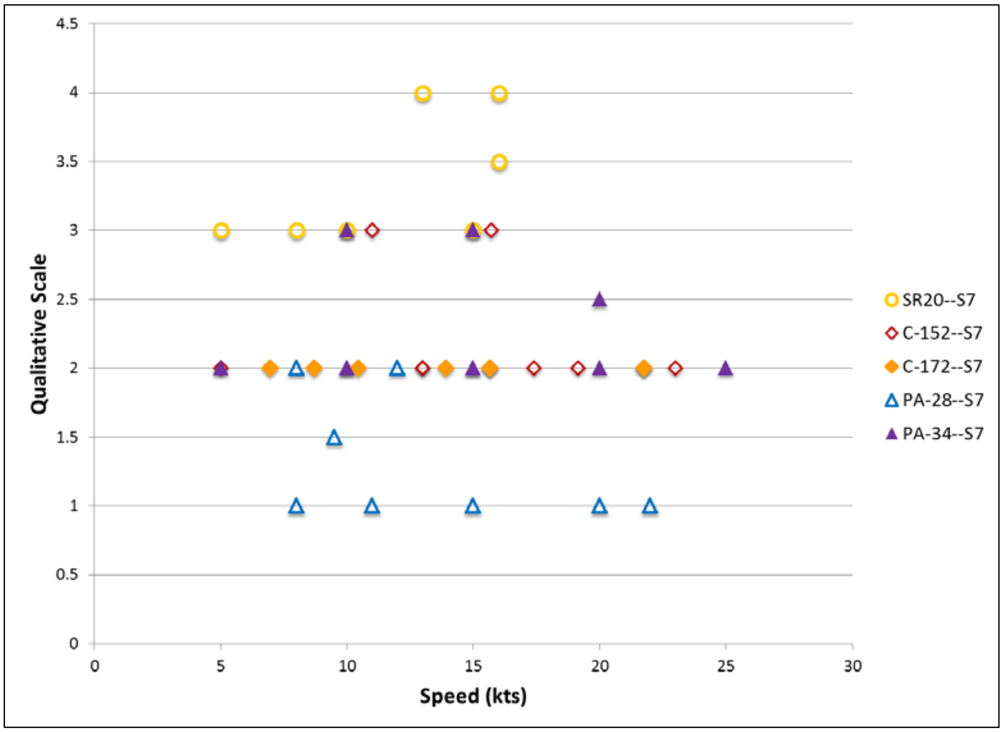
<u>5. RESULTS</u>.

A summary of all of the qualitative ratings is shown in figure 7(a) and (b) for the raised and sawcut rumble strip configurations. Higher ratings are indicative of greater impact. Other than the Piper PA-28 Warrior, the ratings for all aircraft were 2 or greater, indicating that the rumble effects were noticeable at all speeds. The ratings vary depending on the aircraft and the speed, and multiple trials of the same aircraft at the same speed sometimes resulted in different ratings. The highest qualitative ratings were observed between 12 and 15 kt for both the raised and sawcut rumble strips. The rumble effects were most noticeable in the Cirrus SR20 aircraft, perhaps because it was the only one that had a spring steel nose gear plus the second heaviest GA aircraft tested (table 3).

A summary of the acceleration range for the summary vector representing total acceleration in all three directions is shown in figure 8 for the raised and sawcut rumble strip configurations. A higher acceleration range indicates greater variance in aircraft dynamics. As was the case for the qualitative ratings, the values varied depending on the aircraft and the speed, and multiple trials of the same aircraft at the same speed sometimes resulted in different values. The Piper PA-34 Seneca had the highest acceleration range, observed when taxiing at a speed of approximately 15 kt on the raised rumble strip configuration and at 25 kt on the sawcut rumble strip configuration; this could have been because this aircraft was the heaviest (table 3).

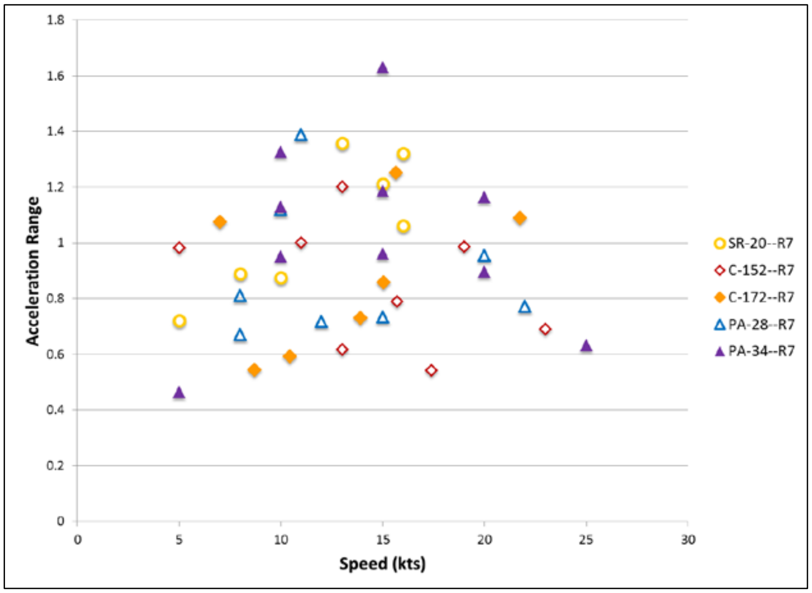


(a) Raised Rumble

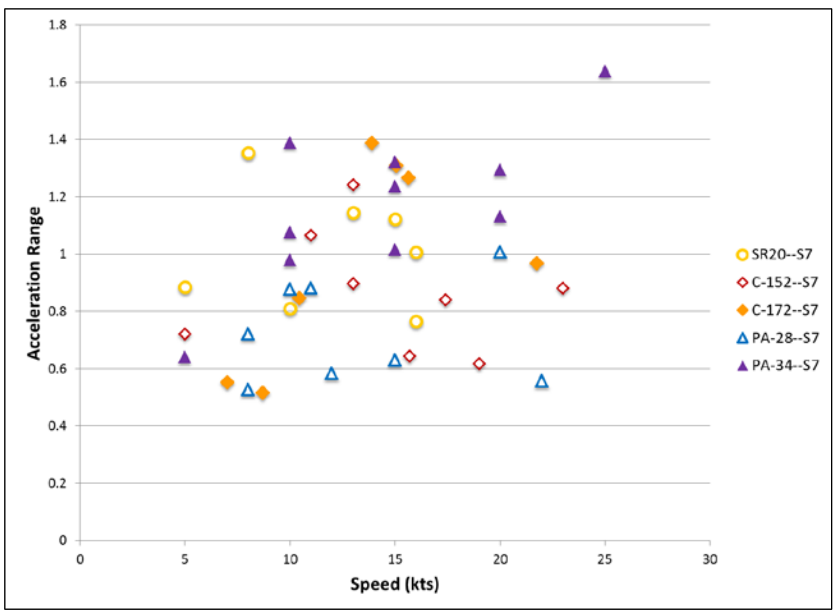


(b) Sawcut Rumble

Figure 7. Qualitative Rating by Right-Seat Observer



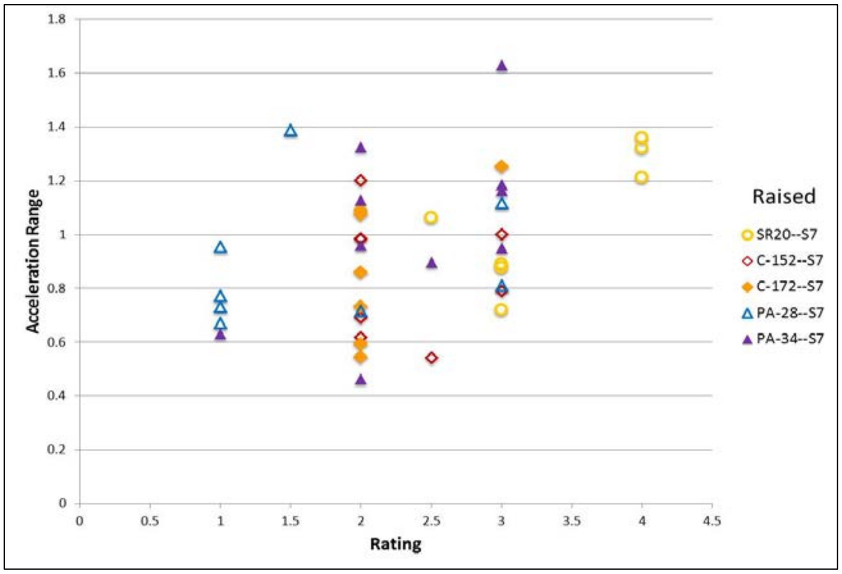
(a) Raised Rumble



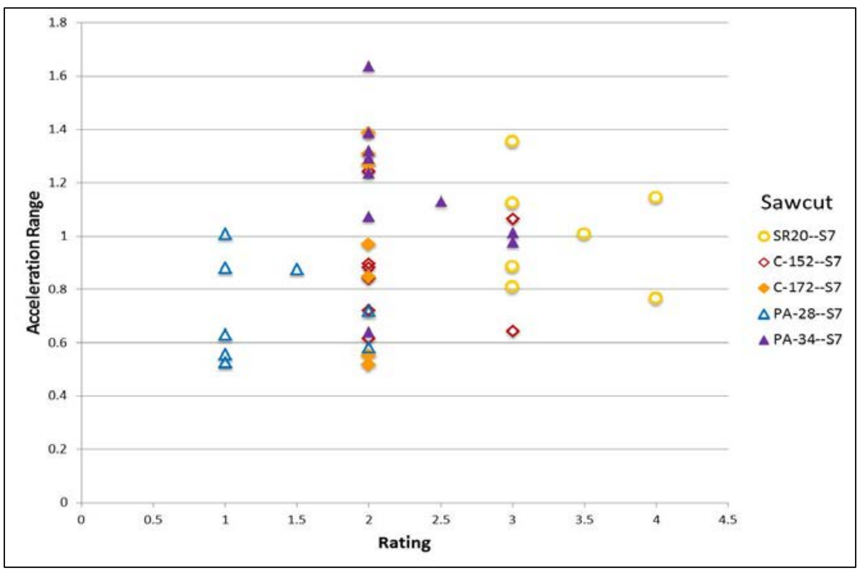
(b) Sawcut Rumble

Figure 8. Acceleration Range per Accelerometer Mounted on Seat Frame
(Total Acceleration in Three Axes.)

Figure 9(a) and (b) shows that these trials had a rating of 3 and 2. The rating of 2 was counter to expectation, because the general assumption was that greater acceleration would correlate with a higher rating. Since the accelerometer was mounted on the seat strut, it is possible that some forces were absorbed by the seat strut itself, diminishing the impact felt by the observer. Other factors, such as the frequency of the vibration and the number of oscillations over a certain magnitude, may have also played an important role in the rating.



(a) Raised Rumble



(b) Sawcut Rumble

Figure 9. Acceleration Range vs Qualitative Rating for Raised and Sawcut Rumble Strips

Figure 9(a) and (b) also shows a general relationship between the acceleration range and qualitative ranking; perhaps more importantly, the figure suggests that the GA aircraft type has a significant influence on the observer qualitative rating. For example, examining the results for the raised rumble strips figure 9(a), the Piper PA-28 Warrior was rated 1 for a trial with an acceleration range of 0.7 (speed 8 kt), whereas the Cirrus SR20 was rated 3 for an acceleration range of 0.7 (speed 5 kt). Similarly, examining the results for the sawcut rumble strips (figure 9(b)), the Piper PA-28 Warrior was rated 1 for two trials with acceleration range values of 0.6 and 0.9 (speeds 15 and 11 kt, respectively), whereas the Cirrus SR20 was rated 4 for an acceleration range just under 0.8 (speed 16 kt).

6. CONCLUSION.

This report presents a framework for the preliminary assessment of aviation rumble strips, including qualitative and quantitative analysis of raised and sawcut rumble strip configurations during non-winter conditions by GA aircraft. Preliminary results may suggest that for certain GA aircraft (limited due to the wide documented variance in results), aviation rumble strips may be a potentially effective tool to provide vibratory feedback to increase situational awareness of an upcoming runway intersection or airport hot spot.

7. FUTURE WORK.

Preliminary results for certain GA aircraft may suggest further refinement of aviation rumble strip geometry (width, depth, and spacing) and expanded test protocol to account for seasonal changes in weather are warranted. Rumble strip edge details also warrant further study to ensure that aviation rumble strips are compatible with snow removal activities, particularly plowing and brooming operations, and their effect on the integrity of the rumble strip being evaluated. Subsequent refinements should be evaluated with an expanded test fleet, with repeated runs to reduce the impact of stochastic variance on both the qualitative and quantitative data, and to confirm if there is a more effective configuration. Additional research may also be valuable to quantify in greater detail the relationship between speed, acceleration, and rating for a wider range of heavier aircraft.

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APPENDIX A—ACCELERATION GRAPHS OF ALL TEST RUNS

Acceleration graphs of all test runs are shown in figures A-1 through A-24.

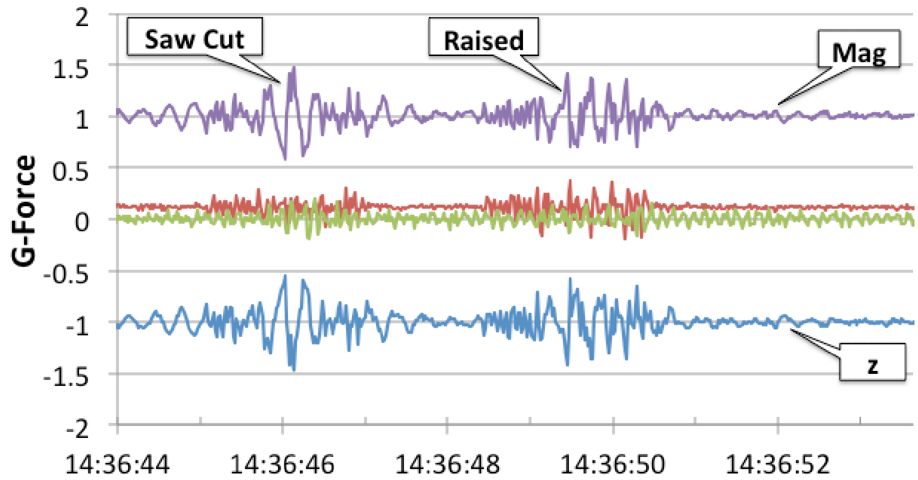

Figure A-1. Cirrus SR20 (5 kt)

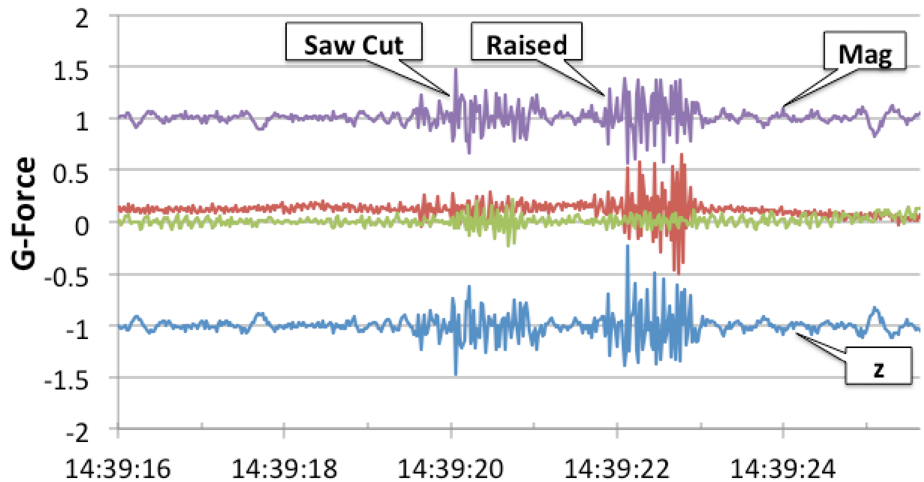

Figure A-2. Cirrus SR20 (10 kt)

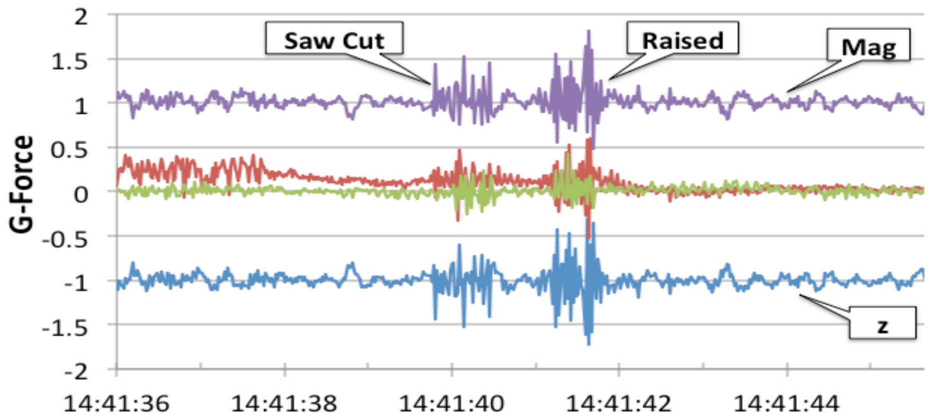

Figure A-3. Cirrus SR20 (15 kt)

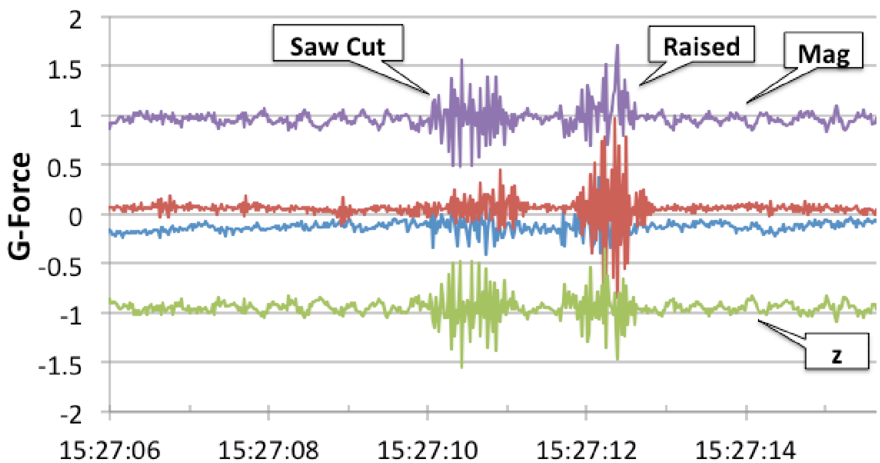

Figure A-4. Cessna 152 (10 kt)

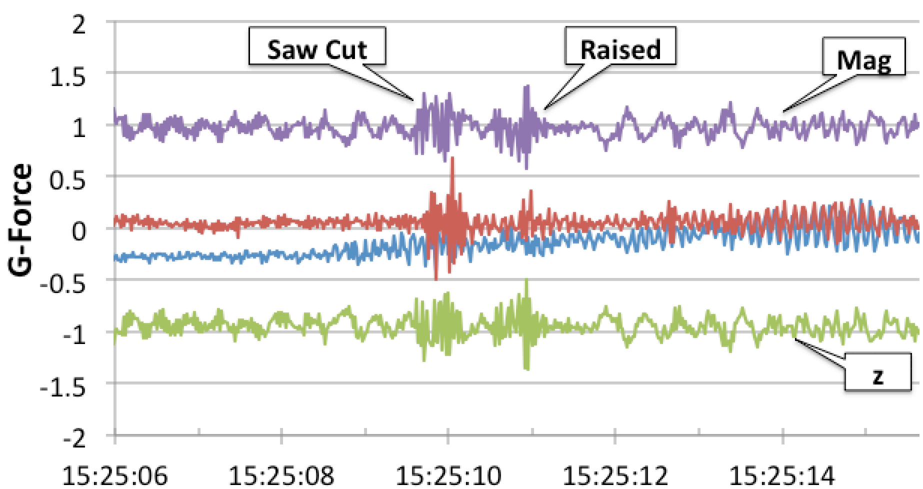

Figure A-5. Cessna 152 (15 kt)

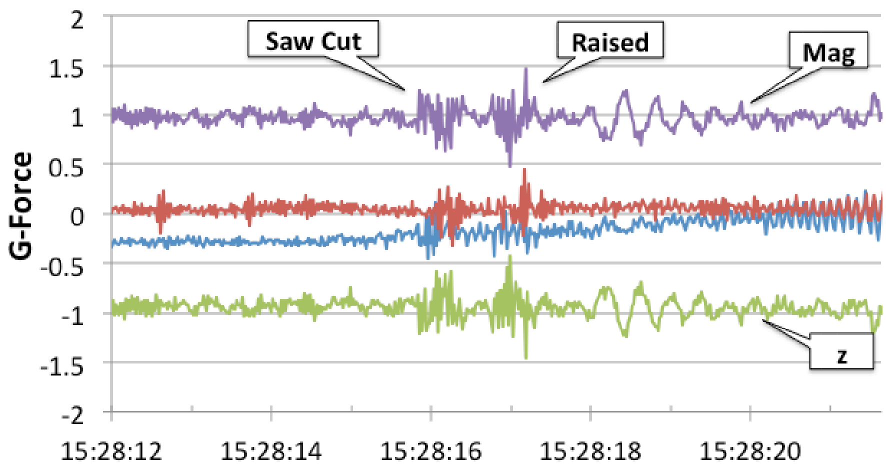

Figure A-6. Cessna 152 (20 kt)

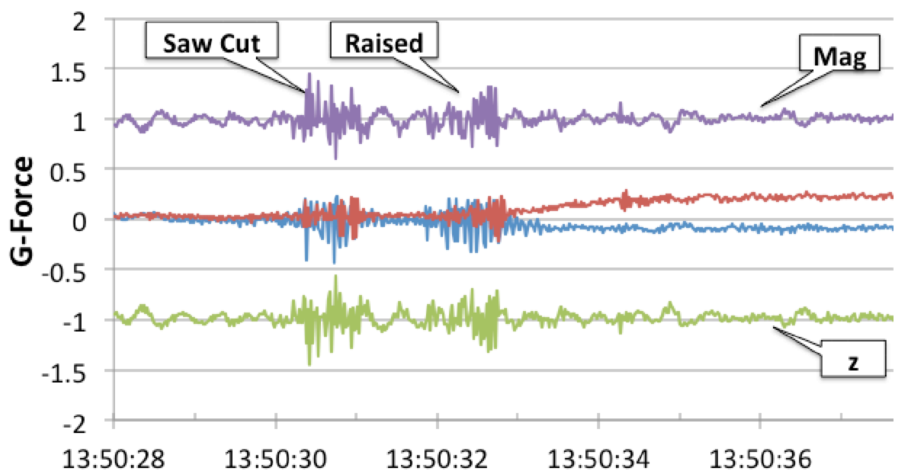

Figure A-7. Cessna 172 (10 kt)

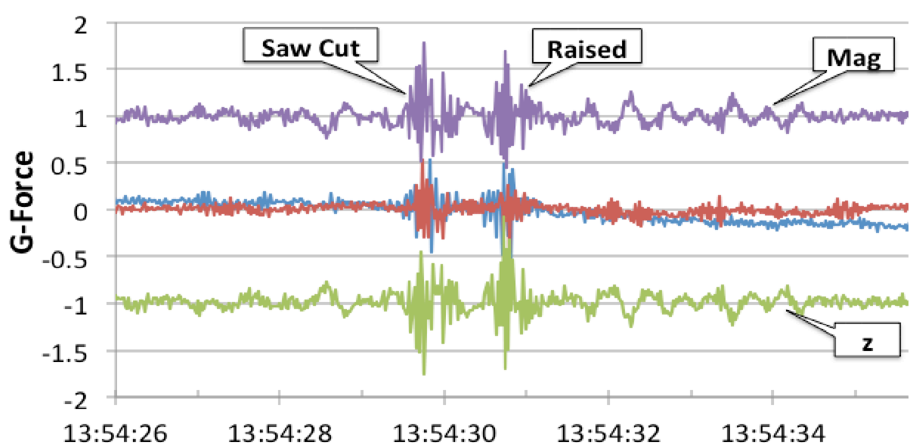

Figure A-8. Cessna 172 (15 kt)

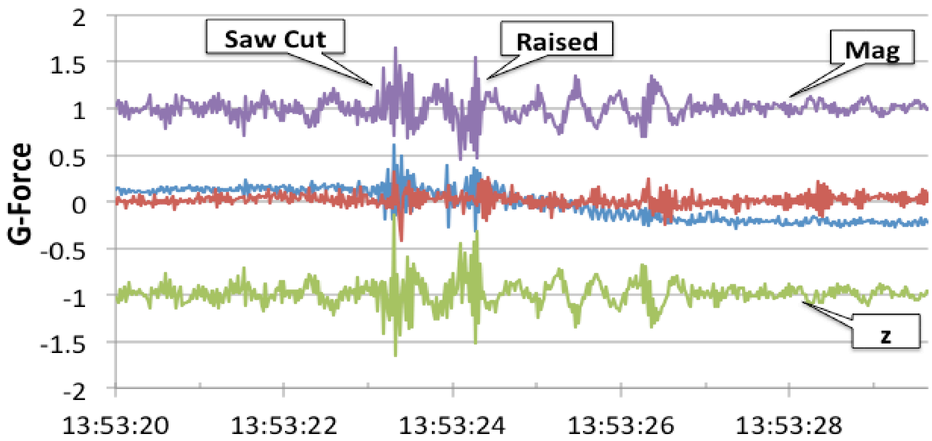

Figure A-9. Cessna 172 (20 kt)

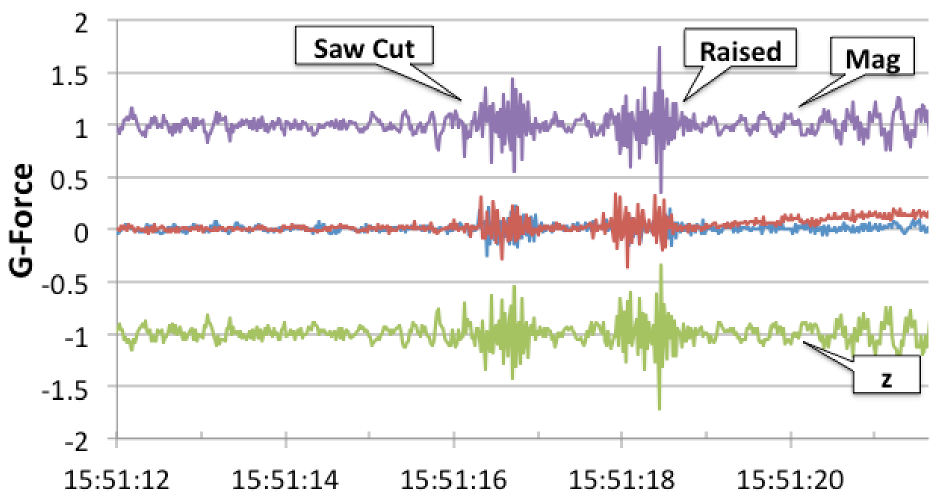

Figure A-10. Piper PA-28 Warrior (10 kt)

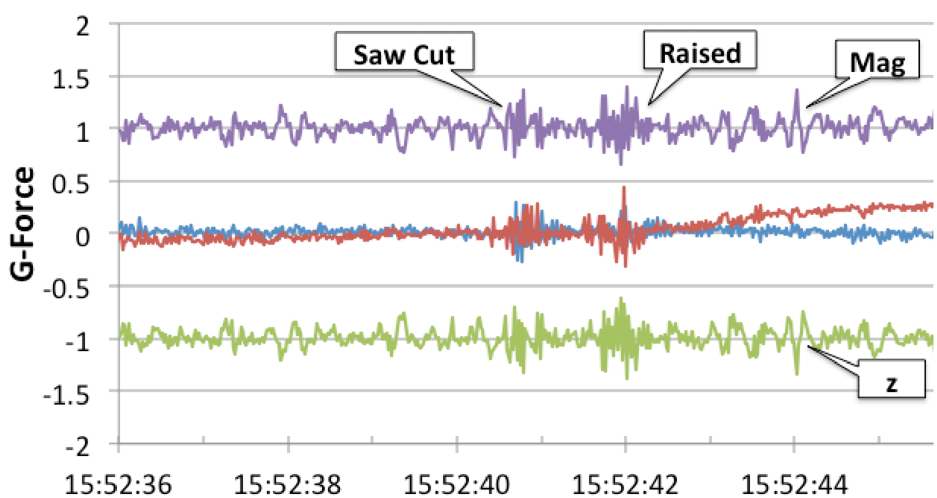

Figure A-11. Piper PA-28 Warrior (15 kt)

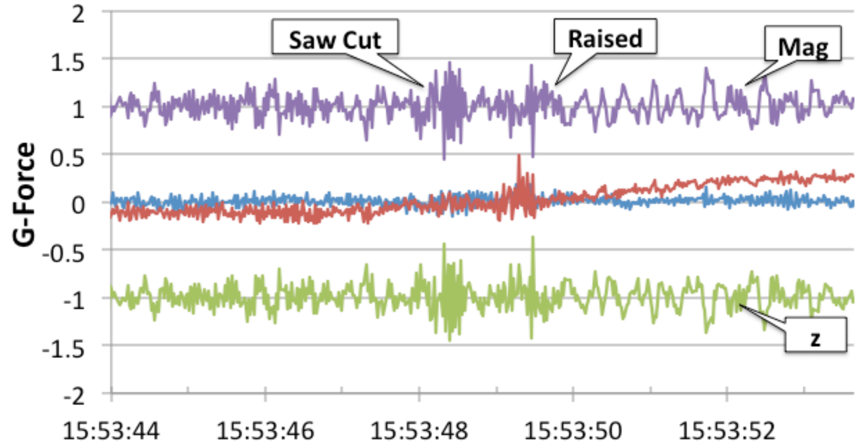

Figure A-12. Piper PA-28 Warrior (20 kt)

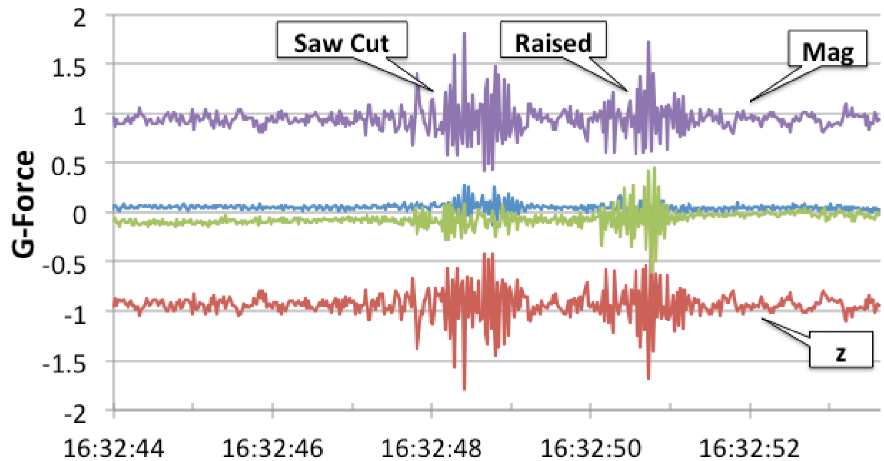

Figure A-13. Piper PA-34 Seneca (10 kt)

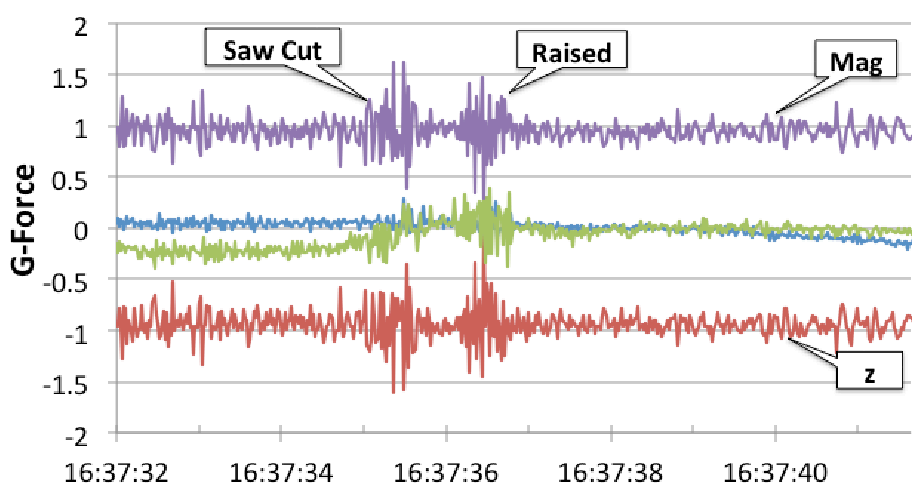

Figure A-14. Piper PA-34 Seneca (15 kt)

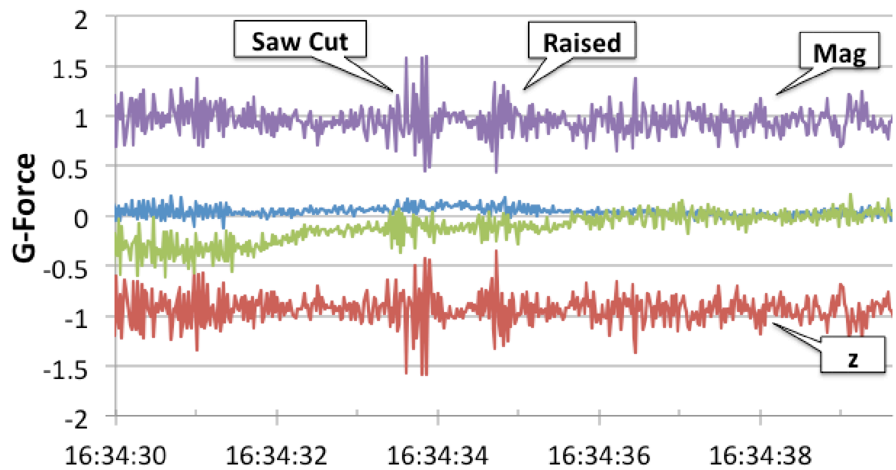

Figure A-15. Piper PA-34 Seneca (20 kt)

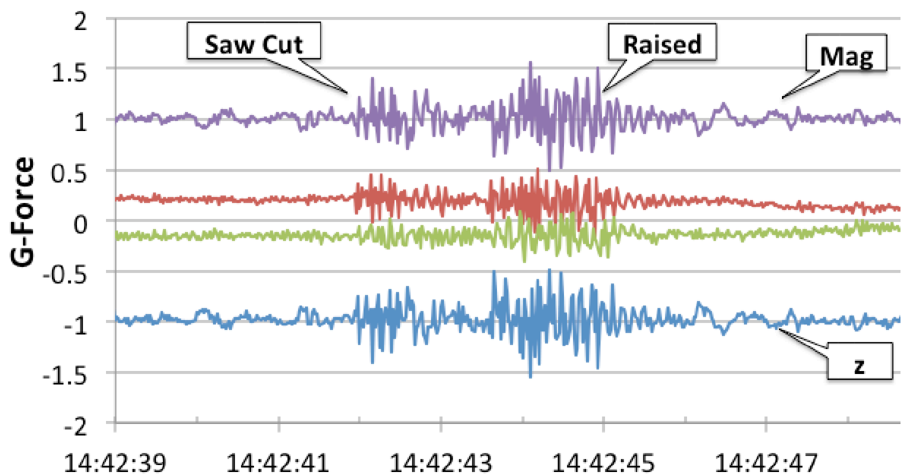

Figure A-16. Ford F250 Pick-up Truck (10 kt)

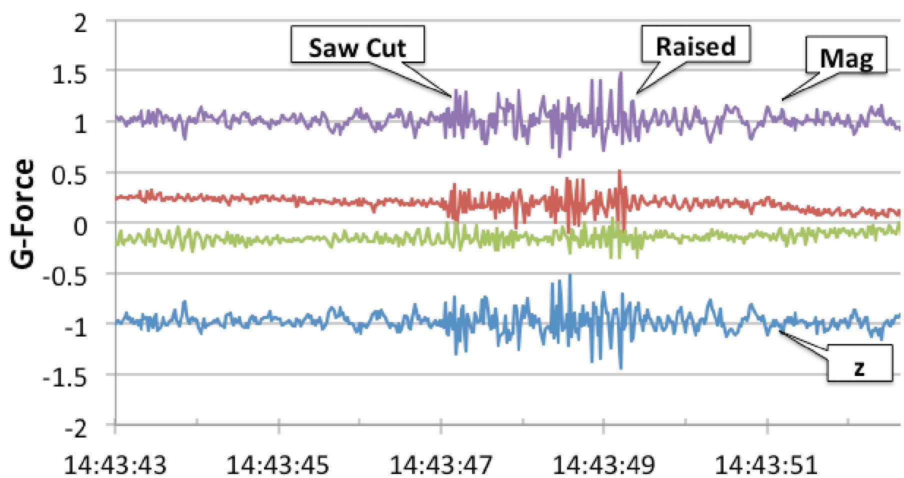

Figure A-17. Ford F250 Pick-up Truck (15 kt)

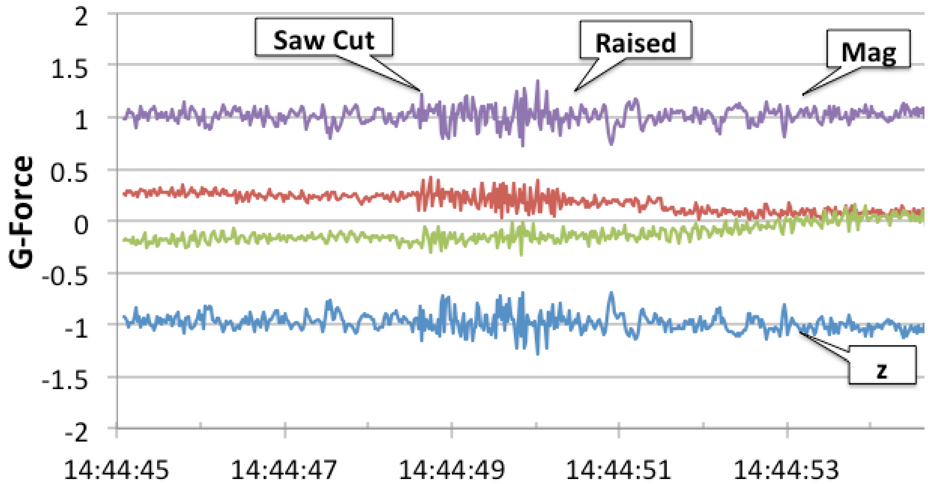

Figure A-18. Ford F250 Pick-up Truck (20 kt)

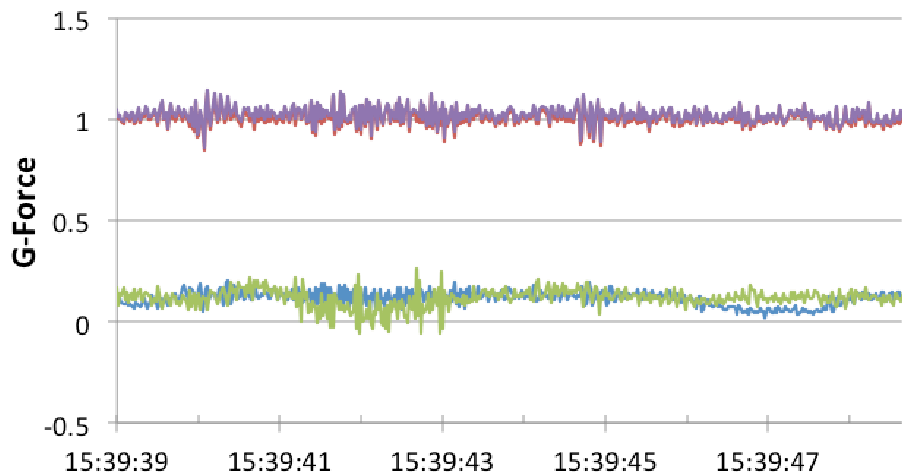

Figure A-19. Centerline Rumble Strip Ford F250 Pick-up Truck 50 mph (43.5 kt)

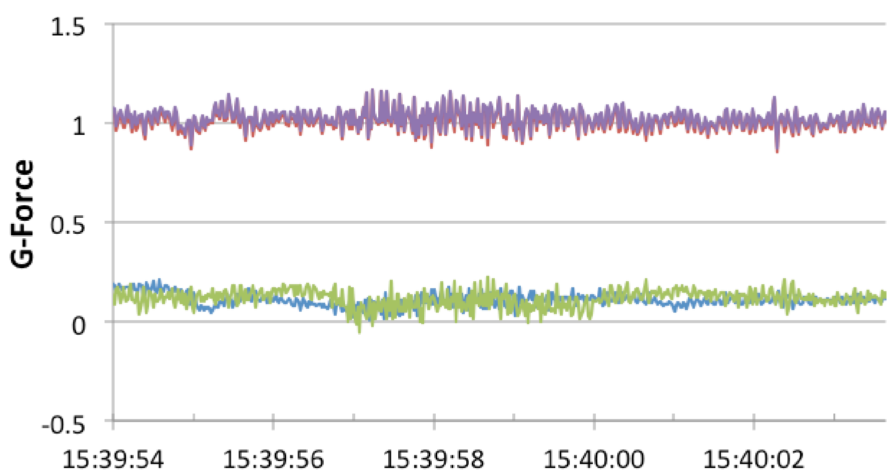

Figure A-20. Centerline Rumble Strip Ford F250 Pick-up Truck 60 mph (52.2 kt)

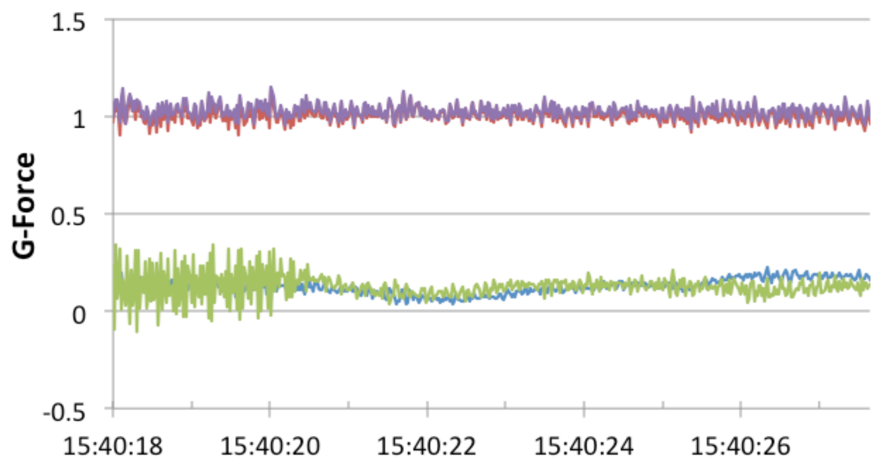

Figure A-21. Shoulder Rumble Strip Ford F250 Pick-up Truck 50 mph (43.5 kt)

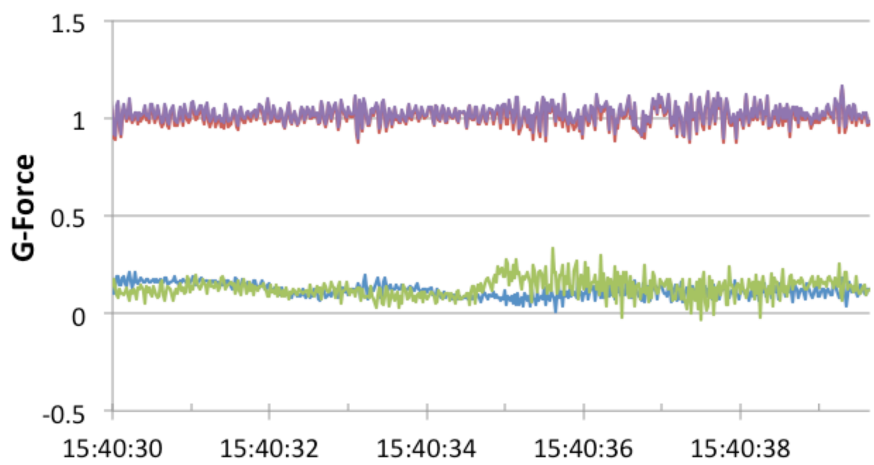

Figure A-22. Shoulder Rumble Strip Ford F250 Pick-up Truck 60 mph (52.2 kt)

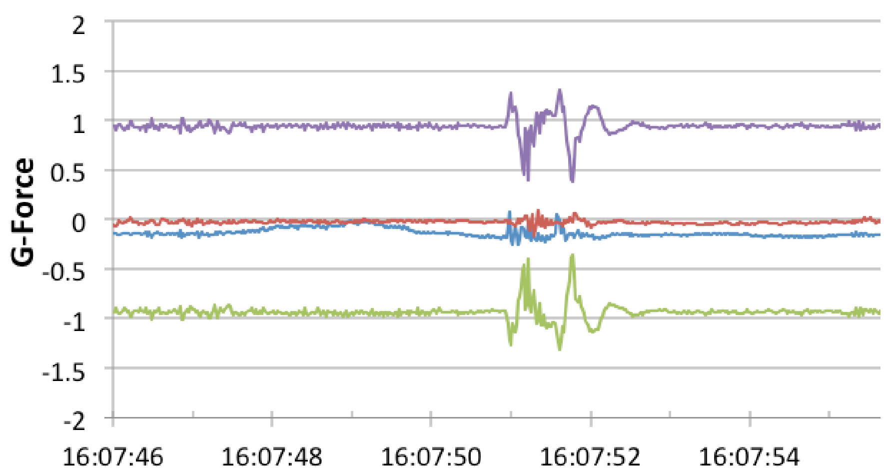

Figure A-23. Speed Bump Ford F250 Pick-up Truck 10 mph (8.7 kt)

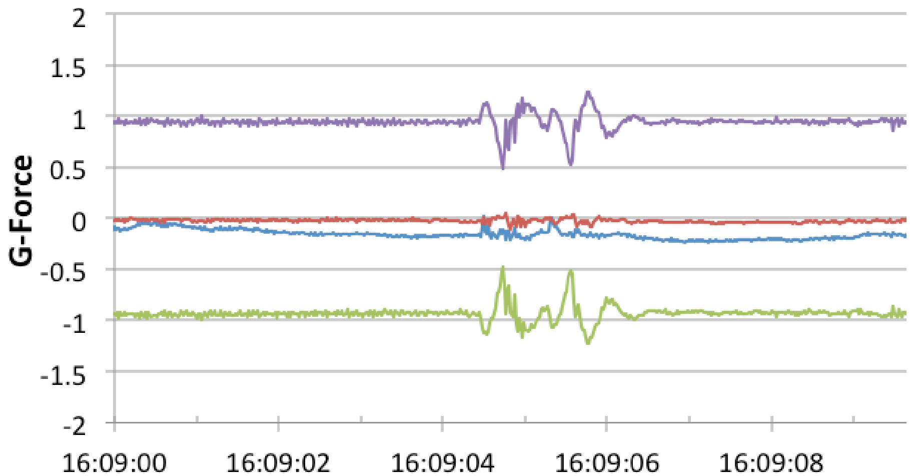

Figure A-24. Speed Bump Ford F250 Pick-up Truck 15 mph (13 kt)