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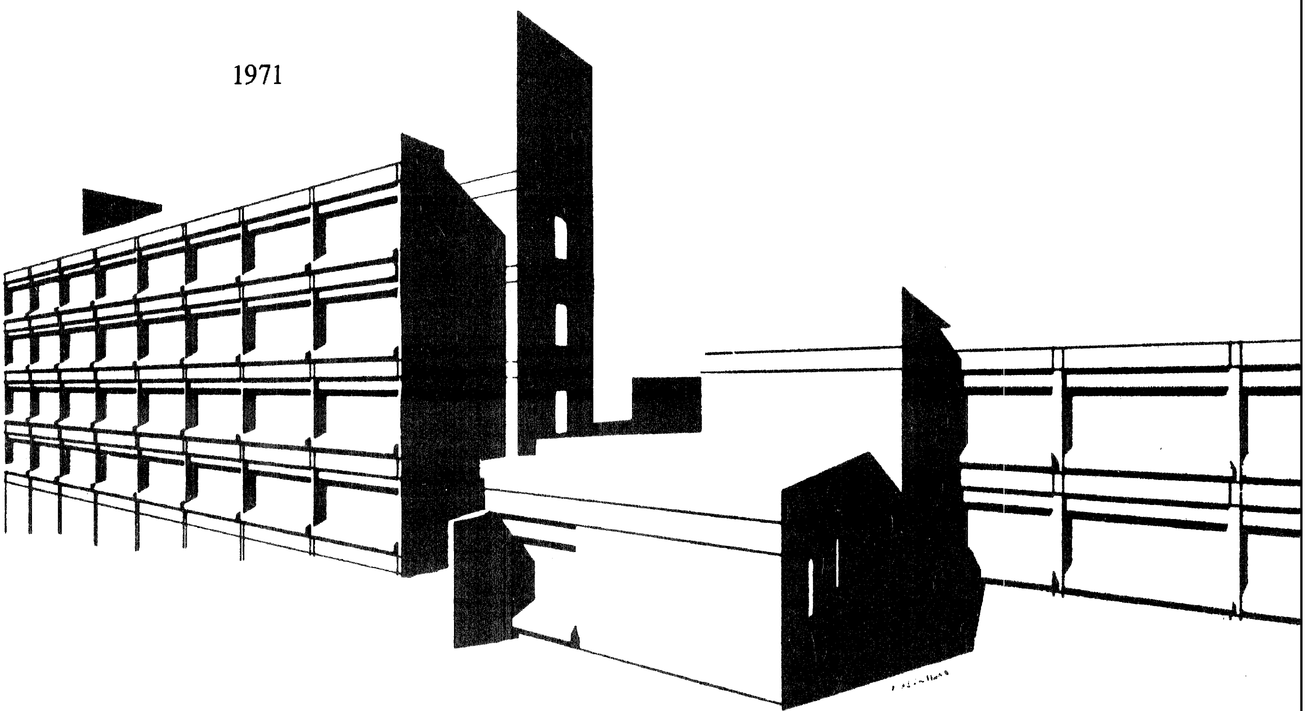

HIGHWAY SAFETY RESEARCH INSTITUTE
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BIOMECHANICS OF SNOWMOBILE SPINE INJURIES

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Many of the seats tested were provided by the snowmobile manufacturers. These companies are: Bombardier, Ltd., SnoJet, Inc., Polaris Industries, Evinrude Motors, Coleman Co., Rupp Industries, and Scorpion Inc. In addition, Arctic Enterprises provided two seats and a snowmobile. The authors thank these people for their willing assistance.

INTRODUCTION

With the increased popularity of snowmobiling as a winter recreational pastime has come an alarming and ever-increasing number of injuries to snowmobile operators and riders. Investigators have compiled accident reports in an effort to document this problem (1,2). These accident statistics indicate that compression fractures of the spine make up a particularly significant class of snowmobile injuries and are especially menacing because of the threat of permanent paralysis. Such fractures are reported to be a common result of either intended or inadvertent jumping of the vehicle.

The mechanics of vertical fall and impact were studied by dropping an instrumented anthropometric dummy with a snowmobile to which a variety of seats from the ten best-selling snowmobile makes were attached. The seats were also loaded in a materials testing machine to determine their individual load-deflection characteristics. For assessment of injury potential, both the drop and seat tests were analyzed using knowledge of human tolerance to vertical loading of the spine gained in studies of the problem of aircraft ejection.

METHODS

The experimental program consisted of two series of tests. In the first series, selected snowmobile seats were individually attached to a snowmobile and with an instrumented dummy in the driver's position the snowmobile, seat, and dummy were dropped. This series lead to a better understanding of the interaction between rider and machine in a vertical fall. In the second series, the seats were isolated and tested in order to study their performance without interference from the machine or the rider.

The snowmobile drop test simulates a snowmobile jump or fall, thus allowing controlled observation and analysis of the occurrences which lead to back injury. The test is based on the fact that a vertical drop is dynamically equivalent to a jump or fall which occurs at a constant horizontal speed.

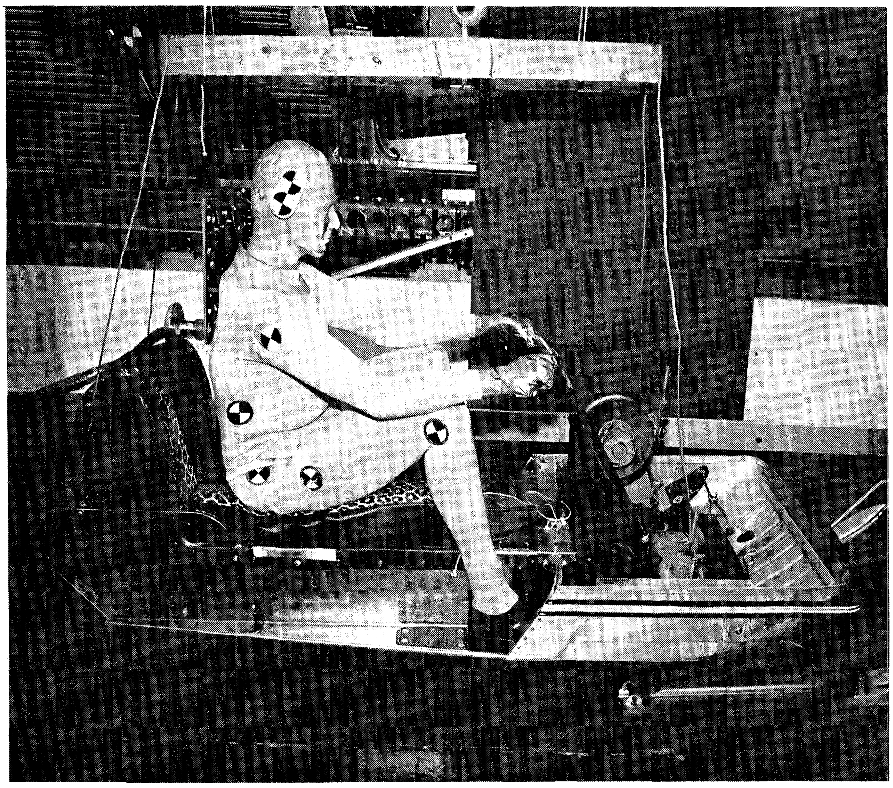

Figure 1. Snowmobile Drop Test Setup

An Arctic Cat Panther snowmobile was used for the testing as shown in Figure 1. The engine and front cowl had been removed, and fifty pounds of lead ballast were placed in the engine location to bring the machine weight up to its normal operating weight of 340 lb. An accelerometer was mounted on the foot board of the snowmobile in line with the middle of the seat. Prior to testing, one of the twelve seats studied in this series was mounted on the snowmobile. The seats were from 1971 models of the ten snowmobile makes which sold best in the 1969-70 season (3). A 95th percentile male Sierra anthropometric dummy weighing 225 lb. was positioned on the machine with its hands taped to the handle bars. The dummy head and torso were each instrumented to sense accelerations in the vertical, fore-aft, and transverse directions. In accordance with standard impact test practice, the dummy joints were set to support the limbs against gravity. The snowmobile suspension was adjusted so that a 50 lb. load applied to the extreme rear of the snowmobile was necessary to overcome the suspension spring preload. This setting corresponded to 1 1/2 in. and 1 in. of exposed threads on the front and rear suspension setting respectively.

The snowmobile with the dummy in place was hoisted to the test height and released to fall onto a concrete floor. The data recorded during each test were acceleration-time traces from the instrumented dummy and snowmobile frame, photographs taken with a Graph Chek sequential Poloroid Camera, and, in two cases, high speed motion pictures.

The impact dynamics of a snowmobile with a rider landing on a horizontal surface after a fall or jump involve many factors: (1) attitude and motion of the snowmobile at impact; (2) attitude and motion of the rider at impact; (3) the weight and center of gravity of the snowmobile; (4) the weight of the rider; (5) the energy absorbing mechanism between the snowmobile and the impact surface; and, (6) the energy absorbing material between the rider and the snowmobile. The first five factors have been held constant in the drop testing. The sixth factor, the seat, is critical to the protection of the rider. The results of the drop testing are presented below, but one observation is presented here due to its significance to the role of a snowmobile seat. In all the drop tests, the snowmobile suspension was bottomed or rebounding when the dummy was deforming the seat to the fullest extent. This means that the seats must absorb much of the energy of the falling rider if injury is to be avoided.

Sixteen seats were tested statically in a Universal testing machine to determine their energy absorbing characteristics. The seats were placed on a large plywood sheet on the movable crosshead of an Instron materials test machine and raised against a one-foot square piece of plywood which was attached to a rigidly held load cell. The deformation of the seat and the load transmitted through the seat were recorded. Four of the seats tested, the Ski-Doo TNT 18 in., TNT 15 in. and Elan seats, and the Arctic Cat Puma, were slanted so that they were thicker at the back than at the front. The slanted Ski-Doo seats were tested in three positions with the load being applied to the front, middle, the rear of the seats. The Arctic Cat Puma seat was shorter and was tested in one position with the edge of the loading surface approximately 1 in. in front of the sharp rise at the rear of the seat. Tests were performed with the seats at temperatures of 70°F and 10°F. A typical load-deformation trace is shown in Figure 2. As the seat was deformed the load transmitted through the seat first increased non-linearly and then increased very rapidly as the seat bottomed.

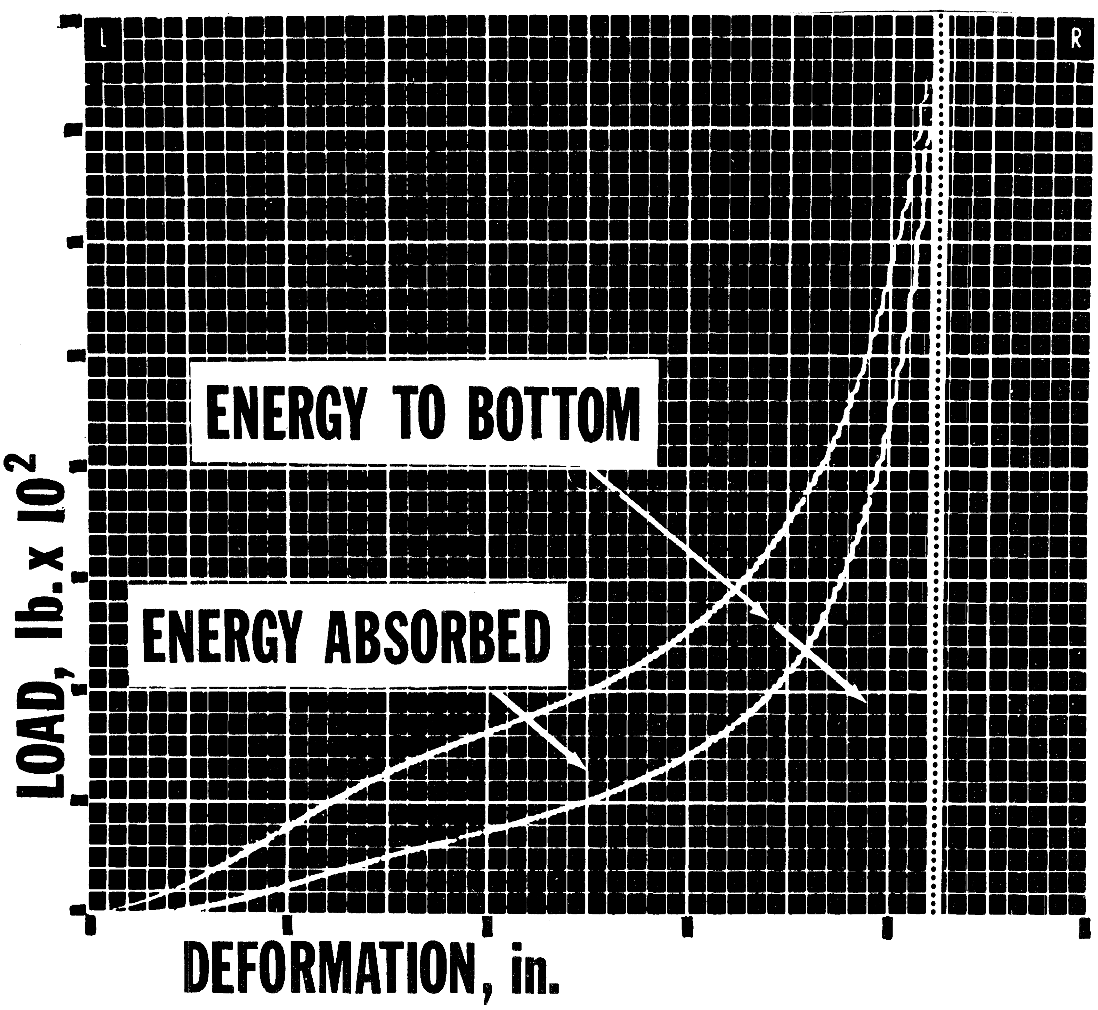

Figure 2. Typical Snowmobile Seat Load-Deformation Trace

RESULTS

A typical drop test is shown in the sequential photograph of test number Z028 (Fig. 3) in which a Scorpion Stinger seat is attached to the test machine.

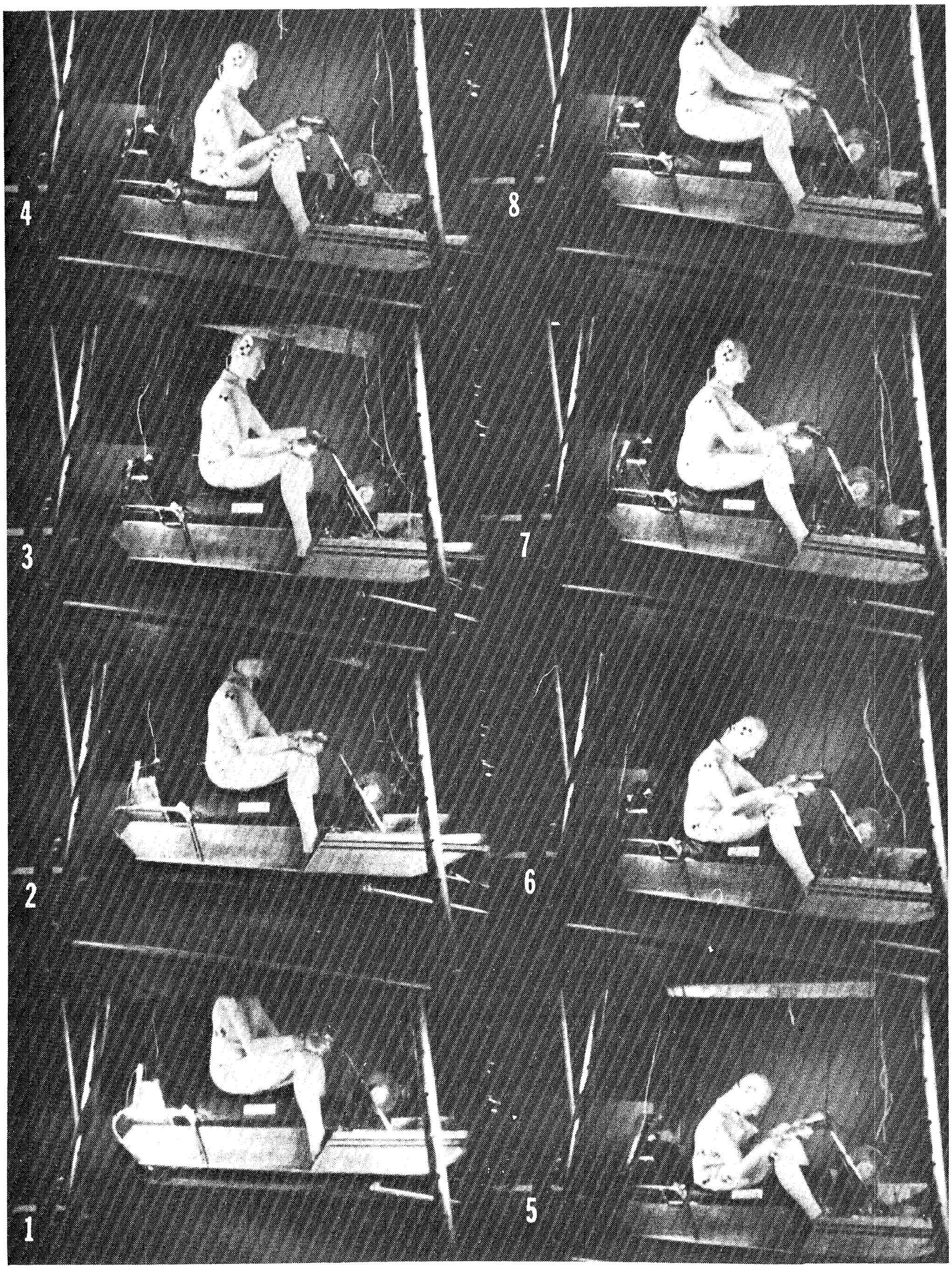

Figure 3. Typical Snowmobile Drop Test Sequence

The sequence starts in the lower left frame and proceeds up the left side to frame 4, then to the lower right frame 5, up the right side, and is completed in the upper right frame 8. In the first three frames the snowmobile is falling with the dummy slightly above the seat. Between frames 3 and 4 the track has contacted the floor, and in frame 4 the suspension has bottomed and the dummy is starting to deform the seat. In frame 5 the dummy has extensively deformed the seat as the machine has already begun to rebound. By frame 6 both dummy and machine are rebounding. In frame 7 the track has left the floor as the dummy rebounds further, and in frame 8 the dummy leaves the seat while the track is still off the floor. Of particular note is the fact that the suspension is bottomed or is just beginning to rebound as the dummy is deforming the seat to the maximum. The action shown in Figure 3 was repeated without exception in the other tests.

For the determination of back injury, the acceleration-time records from the instrumented dummy are the most important data. Figure 4 is the acceleration-time record for test number Z018 using the Arctic Cat Panther seat. The significant trace is chest vertical acceleration, third from the top. The time scale runs from right to left and the vertical lines are 10 milliseconds apart. The vertical chest acceleration increased at an average rate of onset of 1200 G/sec to a maximum of 34 G and decreased at approximately the same rate. The acceleration was above 20 G's for 13 msec, and the duration of the total event was 79 msec. When the Polaris seat was used in drop test number Z019 (Fig. 5), the vertical chest acceleration increased at a rate 650 G/sec. to a peak of 20 G. The total duration of the vertical chest acceleration was 88 msec.

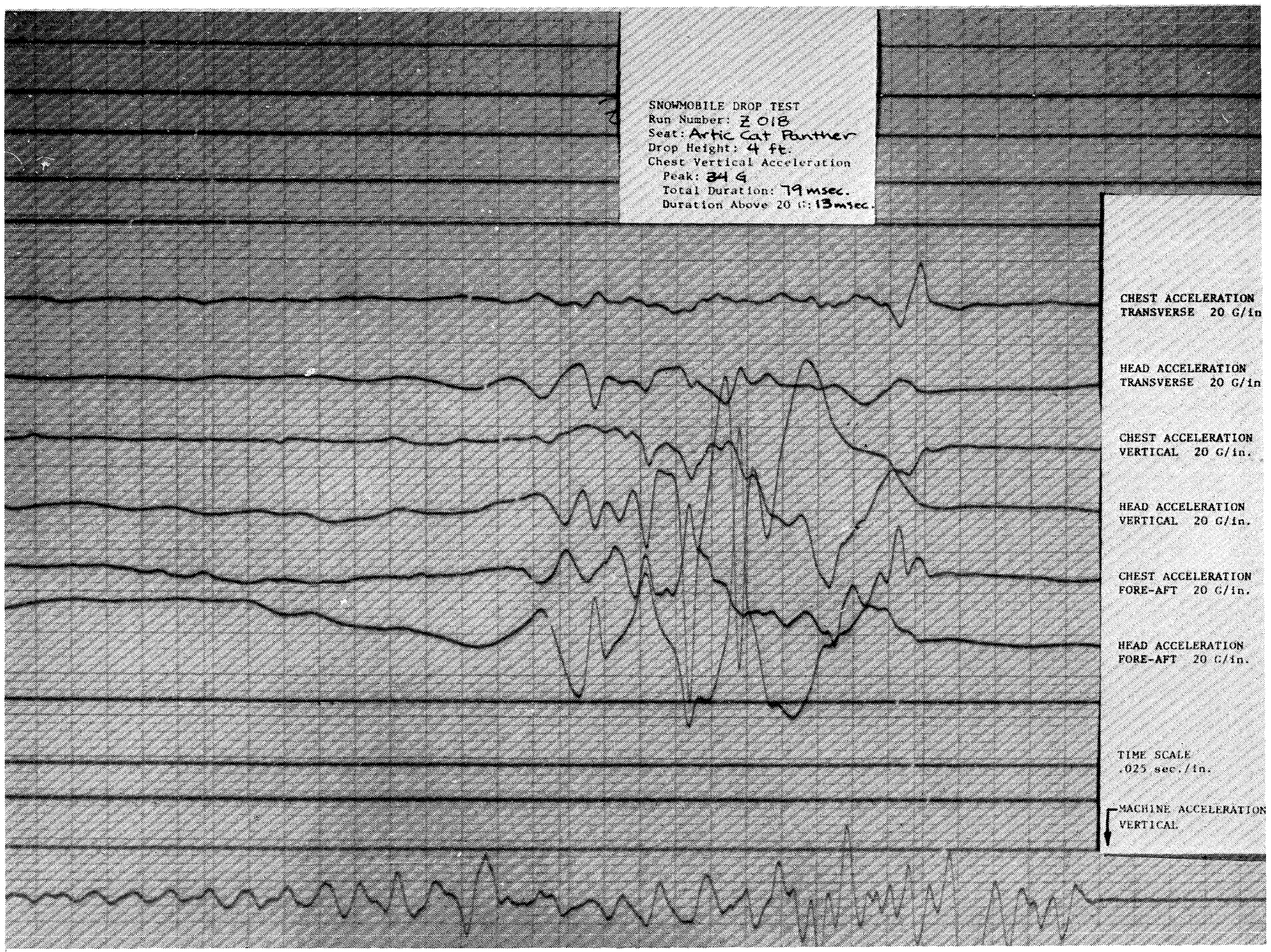

Figure 4. Snowmobile Drop Test Acceleration-Time Record with the Arctic Cat Panther Seat

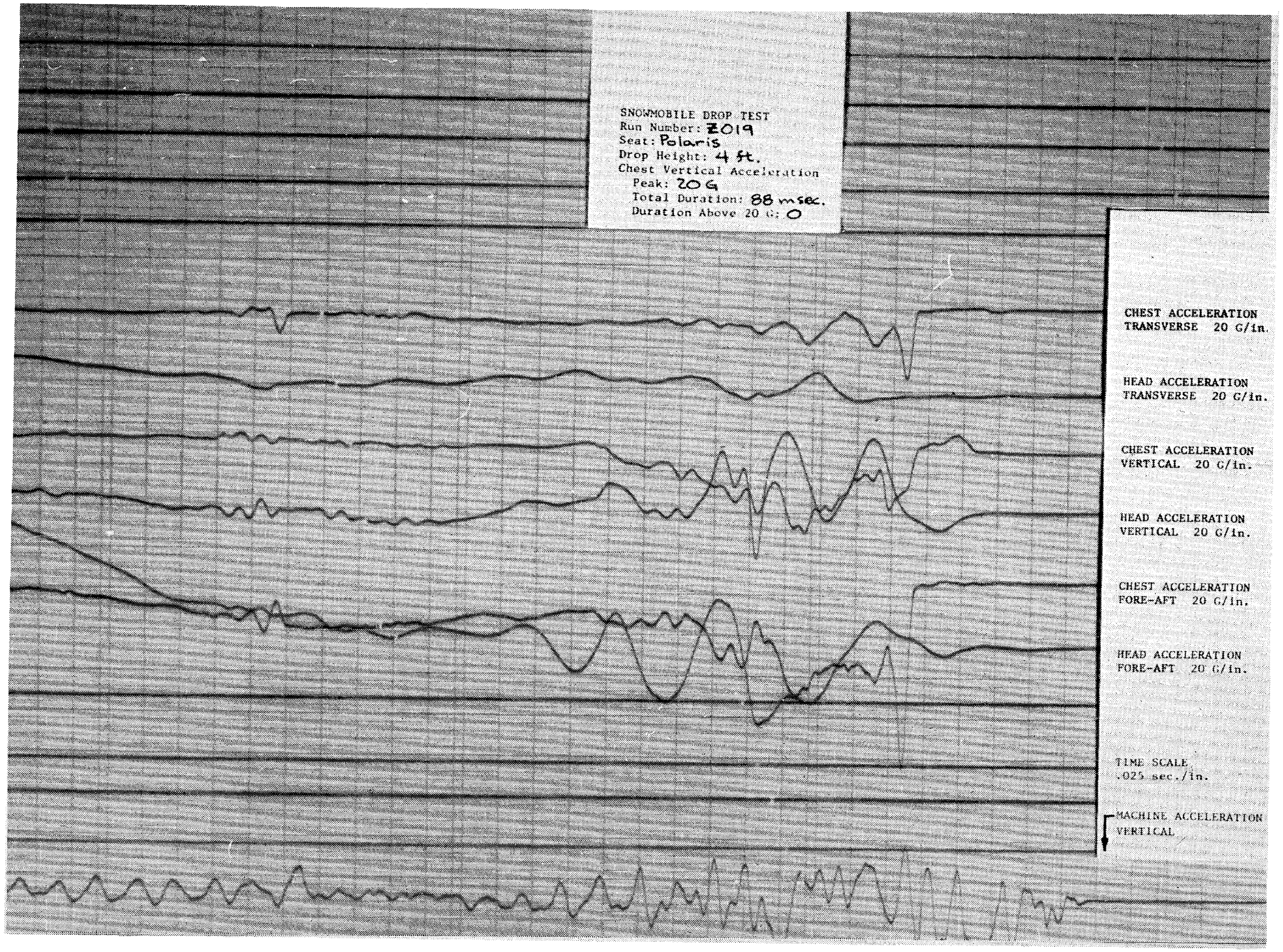

Figure 5. Snowmobile Drop Test Acceleration-Time Record with the Polaris Seat

In order to evaluate these results in terms of snowmobile rider back injury, the levels of human tolerance to upward vertical acceleration must be known. Fortunately human tolerance to this type of impact has been studied in the development of ejection seats for high-speed aircraft. Human tolerance is a function of maximum level of acceleration, duration of acceleration, and rate of onset of acceleration. Investigators have found variation in human impact tolerance, but based on Snyder's review (4) of this subject, levels of acceleration severity greater than 20 G peak, 100 msec. total duration, and 300 G/sec rate of onset will lead to injury of the spine.

Comparison of these tolerance values with the results from two of the fourteen drop tests leads to the conclusion that severe back injury would have occurred in test Z018 of the Arctic Cat Panther seat and back injury probably would have occurred in test Z019 of the Polaris seat.

So that all the snowmobile seats which were drop tested can be evaluated, the test results are listed in Table I. The drop height for all tests was four feet except for the Arctic Cat Panther seat which was tested at additional drop heights of two and three feet. The seats are listed in approximate order of impact severity to the dummy. The two and three foot test of the Arctic Cat Panther seat are listed at the top for comparison with the most severe impact which was the Arctic Cat Panther seat dropped from four feet. Although the total impact durations are all below 100 msec, the peak vertical chest accelerations and rates of onset are high enough to cause injury.

The results for seat testing are summarized in Table II. The deformations to bottom the seats are listed with the loads applied to the seats when there was 1 in. of deformation remaining before bottoming. For three seats, the

TABLE I. SNOWMOBILE DROP TEST RESULTS

Seat	Drop Height (ft.)	Peak Vert. Chest Accel. (G's = 32.2 ft/sec^2)	Rate of Onset (G's/sec.)	Total Duration (millisec.)	Duration Above 20 G (millisec.)
Arctic Cat Panther	2	15	320	88	0
Arctic Cat Panther	3	30	960	94	6
Arctic Cat Panther	4	34	1200	79	13
Evinrude	4	31	930	79	8
Sno Jet Starjet	4	33	1060	87	6
Scorpion Stinger	4	32	980	80	6
Ski-Doo Olympic	4	29	800	75	7
Rupp	4	28	830	76	7
Ski-Doo TNT 18"	4	24	520	87	9
Moto Ski	4	24	640	71	8
Coleman Skiroule	4	22	950	81	7
Arctic Cat Puma	4	23	660	82	4
Alloutte	4	22	1700	72	4
Polaris	4	20	650	88	0

TABLE II. SNOWMOBILE SEAT TEST RESULTS

Seat	Deformation to Bottom (in.)	Load to Bottom (lb.) 1 in. from bottom	Energy to Bottom (in.lb.) 70° F	Energy Absorbed (in.lb.) (10° F)
Arctic Cat Panther	4.5	220	810(895)	353(363)
Evinrude	3.2	280		
Sno Jet Starjet	4.1	340		
Sno Jet SS	3.3	310		
Scorpion Stinger	3.7	300		
Ski-Doo Olympic	4.2	260		
Ski-Doo Nordic	4.6	220	735(814)	168(197)
Rupp	3.2	300		
Ski-Doo TNT 18" front middle rear	4.0 4.6 4.5	280 360 320		
Ski-Doo TNT 15" front middle rear	3.1 3.5 3.8	320 380 370		
Ski-Doo Elan front middle rear	3.5 4.2 4.3	270 310 340		
Moto Ski	3.5	300		
Coleman Skiroule	3.5	340		
Arctic Cat Puma	4.2	280		
Alloutte	3.6	270		
Polaris	5.2	380	1270	497

energy required to bottom them and the energy absorbed by them are listed in Table II. For two of these seats the energies were determined for both 70°F and 10°F. The energy required to bottom the seat is the area between the loading trace and the horizontal axis in Figure 2. The energy absorbed by the seat is the area between the loading trace and the unloading trace. There was very little change in the mechanical response of the seats with temperature. This is evident from the energies listed in Table II for the Arctic Cat Panther and Ski-Doo Nordic seats at both test temperatures. All other data are given at the 70°F test temperature.

The order of listing for Table II is the same as for Table I; that is, the seats are listed in decreasing order of impact severity based on the drop tests. The four seats which were not included in the drop tests are listed in Table II with the seat from the same manufacturer which they most nearly resemble. Examination of the load at 1 in. from bottoming indicates that many of the seats were nearly bottomed by the weight of the dummy alone and that the remaining seats approached bottoming with a force less than twice the dummy weight or an upward vertical acceleration of 1 G in addition to gravity. These low seat stiffnesses might be confortable under some snowmobile riding conditions but they leave very little margin for vertical impact protection of the rider.

A 225 lb. rider who is 48 in. from the ground has 10,800 in.lb. of energy. As he falls some of the energy may be dissipated in the rider's muscles if he posts. When he impacts the seat, the energy which is not dissipated by deformation of the seat and the suspension must be dissipated within his body. We have observed in the drop tests that the suspension is either bottomed or rebounding during maximum compression of the snowmobile seat.

Therefore, the seat must absorb most of the rider's energy if he is to avoid injury. Referring to Table II, even in the least severe case of the Polaris, the seat required only 1270 in.lb. of energy to bottom. After bottoming the seat, the rider is very heavily loaded and, in all likelihood, injured.

Because human injury tolerance is not only a function of peak acceleration but also of duration of acceleration, the unloading of the seat as the rider bounces back is very significant. If much of the energy required to deform the seat is dissipated within the seat, then as it is unloaded, the load levels and the acceleration levels will drop sharply leading to a less severe impact. Again, in the least severe case of the Polaris seat, less than half of the energy requried to load the seat is dissipated by it, and this dissipated energy is very small compared to the energy of the falling rider.

SUMMARY AND CONCLUSIONS

The biomechanics of spine injuries to riders who inadvertently or intentionally jump their snowmobiles was studied in two series of tests. In the first series, twelve snowmobile seats were tested. Each seat individually was mounted on the test snowmobile, a fully instrumented anthropometric dummy was placed in the rider's position, and the dummy, seat, and snowmobile were dropped. As the dummy deformed the seat to the maximum extent, the snowmobile suspension was bottomed or rebounding so that the dummy had only the seat to protect it from severe vertical impact. The dummy bottomed the seat and was subjected to 20 G's in the least severe impact and 34 G's in the most severe case. Comparison of drop test results with human tolerance information indicates that the impact severity was sufficient in all cases to cause injury of the spine.

In the second test series, sixteen snowmobile seats were tested to determine their performance independent of the effects of snowmobile and rider. When the seats were deformed by a force equal to the weight of the dummy, they were nearly bottomed, leaving little margin for rider protection to vertical impact. As they were deformed further, the loads increased sharply until the seats became virtually rigid. The seats tested were capable of absorbing only a small part of the rider's energy at impact. The remaining energy must be dissipated within the rider causing injury.

Using presently available technology, snowmobile seats can be designed which will sharply reduce the potential of spinal fracture. Because snowmobile seats are inexpensive relative to the price of the vehicle, they are easily changed in design, and they do not effect the handling characteristics of the vehicle, improved seating could be presented to the snowmobiling public at a minimum of inconvenience.

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