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Ergonomic Study of Snowmobiles

S. Sturgis, R.G. Mortimer
R.W. McCutcheon, C.M. Jorgeson

*Highway Safety Research Institute
University of Michigan
Huron Parkway and Baxter Road
Ann Arbor, Michigan 48105*

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ERGONOMIC STUDY OF SNOWMOBILES

Abstract

One of the most important considerations in the design of machines for human use is the range of body size of the operator population. The present study was undertaken for the purpose of determining the extent of the anthropometric fit between snowmobiles and their users. The need for the investigation was apparent from the variety of snowmobiles that are available. The study revealed a number of areas in which greater consideration of human factors would result in a safer and more comfortable vehicle.

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INTRODUCTION

HISTORY

Although snowmobiles came into existence in 1927 (Briggs, 1965) their popularity as winter sporting vehicles is recent. In the 1962-63 period 10,000 vehicles were produced and sold. Production did not catch up with sales until the 1967-68 season when the number sold was 165,000. In the 1969-70 period 400,000 snowmobiles were sold. Sales of almost one million are predicted for 1972-73 with a rapid growth rate continuing until 1975 when a leveling-off period is expected. The potential snowmobile market is estimated at approximately five million vehicles (Butler, 1970).

In the early days of snowmobiling the primary use was utilitarian (Briggs, 1965). Utility companies, forest rangers, mailmen, doctors, and others who had to get around despite extreme weather conditions used them (Heath, 1968). However, with the advent of two passenger models (Briggs, 1965) and the need to fill a winter outdoor recreational void (Butler, 1970), their popularity grew. In 1968 it was estimated that only 10 percent were being used for utility purposes. Twenty-five percent were purchased by outdoorsmen for hunting, trapping, and ice fishing, and 65 percent were being sold for recreational purposes (Heath, 1968).

Quebec is the most heavily saturated snowmobile area with approximately one out of five households owning at least one machine (Butler, 1970). The most important snowmobiling states in the U.S. are Michigan, Minnesota, Wisconsin and New York, with sales in these states accounting for more than half of all snowmobile sales (Heath, 1968). Mackinac Bridge officials estimated that 50 percent of the vehicles crossing the bridge between upper and lower Michigan during the first week of January were

transporting at least one snowmobile (Government Bulletin, 1969). Their popularity is also high in other states in the snow belt.

With the boom in sales, the number of manufacturers has increased from the original Bombardier Company (Briggs, 1965) to 50 or 60 manufacturers (Butler, 1970) producing about 400 models (Field and Stream, 1969).

SAFETY

The problems involving snowmobiles are critical because of their land use requirements and because their speed and mobility accentuate the necessity of proper use and training by snowmobilers. This brings up the prospect of licensing drivers and vehicles and initiating legislation to control snowmobile use (Government Bulletin, 1969; Mainville, 1969; Family Safety, 1967). Associated with snowmobile use are problems of safety which are compounded because of winter conditions. Accident statistics for snowmobiles indicate a lack of good judgment on the part of many users (Negri, 1970; McLay and Chism, 1969; Medical Tribune, 1968; Traffic Safety for Michigan, 1970; The Minneapolis Star, 1966). Snow covered terrain and objects can cause accidental damage to vehicles and injury to riders. Iced-over lakes and streams invite the snowmobiler with level, unobstructed paths, but the ice may not be able to support the weight of a 300 pound-plus vehicle and its passengers and equipment. Because of the high speeds attainable with these vehicles and their off-the-road capability it is easy to get away from people and help. Cold weather, snow, and blizzards become critical when there are breakdowns in equipment or when riders become stranded or disoriented.

Not only does the snowmobile not constrain participants to a restricted area such as a ski slope or a toboggan run, but it does not require any formal training to use. The informed

and experienced snowmobiler has respect for the vehicle, the terrain, the weather conditions, and other people in the area. Because snowmobiles can differ greatly in their performance and handling, experience with one kind is not necessarily adequate preparation for operating other makes and models.

Industry concern for snowmobile safety has been commendable. At least one manufacturer, in cooperation with the National Safety Council, has prepared a booklet explaining the basic fundamentals of safe operation (*Play Safe*, 1968). The industry has presented at least one paper before the National Safety Congress concerned with snowmobile safety (Mitchell, 1965). At the 1969 International Snowmobile Conference, Harold Howe, ISIA executive secretary stated that "The ISIA membership envisions our most pressing current problems to be safety, state and provincial legislation, and communications throughout the entire industry from manufacturers to users, and also with other organizations working in the same areas."

One of the most important considerations in the design of machines for human use is the range of body size of the operator population. The designer of such equipment must rely heavily on available anthropometric data in order to decide on proper specifications for the machines. An anthropometric approach to the design of snowmobiles is important in reducing accidents by the elimination of awkward body positions, which result in slow and inaccurate control movements and the elimination of dimensions of machines which result in operator muscle strain, back injuries, discomfort and fatigue.

The present study was undertaken for the purpose of determining the extent of the anthropometric fit between snowmobiles and their users. The need for the investigation was apparent from the variety of snowmobiles that are available.

METHOD

SUBJECTS

Three subjects, a female and two males, were selected to represent about the mean stature of females and males and an approximate maximum male operator size. Eight anthropometric measurements (Figure 1) were taken for each of the three subjects (Tables 1-3). In terms of overall anthropometric dimensions, subjects 1 and 2 represent approximately "average" females and males in the civilian population. The third subject's stature was that of a 99th percentile male. These values are based on a civilian population sample for 1960-62 (Damon, Stoudt, McFarland, 1966) and do not necessarily represent the snowmobile user population. However, at present no better sample is available with which to make a comparison.

TABLE 1. SUBJECT ANTHROPOMETRY (SUBJECT 1)

Female	Distance (inches)	Percentile Female Civilian Population (1960-1962)	Percentile Female Air Force Pilots (1944)
<hr/> Dimension			
1. Stature	63.5	59	25
2. Sitting Height	33.75	60	37
3. Sitting Eye Height	29.25		22
4. Forearm-Hand Length	15.50		
5. Hand Length	6.50		13
6. Buttock-Knee Length	22.0	38	27
7. Popliteal Height	15.75	43	
8. Foot Length	9.38		27

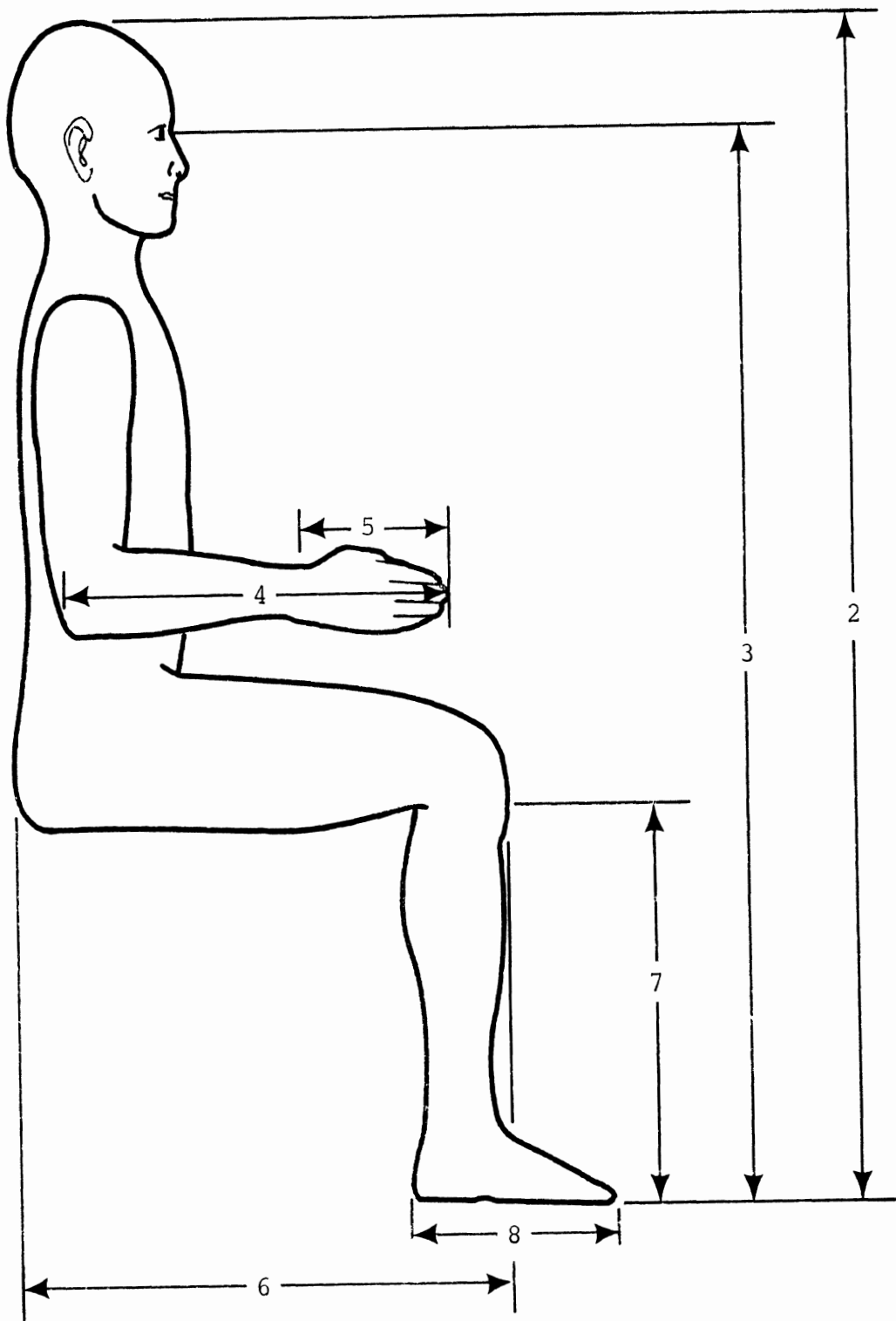


Figure 1. Physical dimensions for the seated body.

TABLE 2. SUBJECT ANTHROPOMETRY (SUBJECT 2)

Male	Distance (inches)	Percentile Male Civilian Population (1960-1962)	Percentile Army Aviators (1959)
Dimension			
1. Stature	68.25	49	35
2. Sitting Height	35.0	31	32
3. Sitting Eye Height	31.0		53
4. Forearm-Hand Length	19.5		68
5. Hand Length	7.75		77
6. Buttock-Knee Length	23.5	57	39
7. Popliteal Height	17.5	56	
8. Foot Length	10.66		55

TABLE 3. SUBJECT ANTHROPOMETRY (SUBJECT 3)

Male	Distance (inches)	Percentile Male Civilian Population (1960-1962)	Percentile Army Aviators (1959)
Dimension			
1. Stature	78.0	99	99
2. Sitting Height	39.0	99	99
3. Sitting Eye Height	33.75		99
4. Forearm-Hand Length	21.5		99
5. Hand Length	9.0		99
6. Buttock-Knee Length	26.88	99	
7. Popliteal Height	19.75	98	
8. Foot Length	12.0		99

THE SNOWMOBILES

Three snowmobiles, an Arctic Enterprises Panther 399, an Evinrude Skeeter 2000, and a Bombardier Ski-Doo Olympique 399 were selected for the survey. The machines were loaned for the study by the dealer at little or no cost. These machines were chosen because they differed substantially in such dimensions as seat height, handgrip to seat top height, angle of handlebar rotation, and windshield and cowl height. Table 4 lists twenty selected dimensions for each machine. Figure 2 shows the dimensions measured.

PROCEDURE

A three-dimensional grid measuring 6 x 6 x 9 feet with major markings at one-foot intervals and minor markings at two-inch intervals was constructed on the two walls and floor of the corner of a large garage. This grid was used as a background against which the subjects and the machines were photographed. Two Nikon 35-mm cameras with 50-mm lenses and color slide film were used in the photography.

Selected dimensions of the snowmobile were measured to provide information which could be compared with anthropometric data to determine the extent to which these dimensions met anthropometric criteria. Each subject was photographed on each vehicle in six positions shown in Figures 3-8. 1) sitting alone, straight ahead position, 2) sitting alone, full turn, 3) sitting with passenger, straight ahead position, 4) sitting with passenger, full turn, 5) kneeling alone, straight ahead position, and 6) kneeling alone, full turn.

Each of the two cameras used was kept at a constant position throughout the survey, three feet from the floor and twenty feet from its respective wall, bisecting the subject and machine frontally and laterally. Thus, two views were

TABLE 4. SELECTED MEASUREMENTS FROM SNOWMOBILE SAMPLE

	Artic Enterprises Panther 399	Evinrude Skeeter 2000	Bombardier Ski-Doo Olympique 399
1. Overall length	106.0"	101.0"	98.0"
2. Top of seat to highest point on footrest	14.0"	14.5"	10.0"
3. Seat length	29.0"	32.0"	32.5"
4. Handgrip to seat top	Neutral	9.0"	13.5"
	Full Rt.	6.0"	8.75"
	Full Lt.	15.0"	21.5"
5. Cowling top to seat top	8.5"	15.25"	16.0"
6. Windshield top to seat top	20.5"	28.5"	26.5"
7. Handgrip to seat front	4.0"	4.5"	1.0"
8. Steering column hub to seat front	8.5"	10.0"	5.75"
9. Cowling top to seat front	17.5"	20.0"	8.75"
10. Windshield top to seat front	23.0"	10.5"	10.5"
11. Angle of steering column (from horizontal)	65°	35°	52°
12. Seat width	18.5"	17.25"	16.5"
13. Footrest width	(a) Front	5.5"	5.0"
	(b) Center	3.75"	3.5"
	(c) Rear	1.5"	2.0"
14. Footrest span	(a) Front	30.0"	32.0"
	(b) Center	26.0"	28.5"
15. Grip to grip span of handlebar	21.75"	23.5"	22.25"
16. Angle of handlebar rotation	140°	98°	80°
17. Handlebar grip diameter	1.5"	1.38	1.88
18. Brake control location	Forward left side of handlebar		
19. Throttle control location	Rear right side of handlebar		
20. Weight	330 lbs.	431 lbs.	320 lbs.

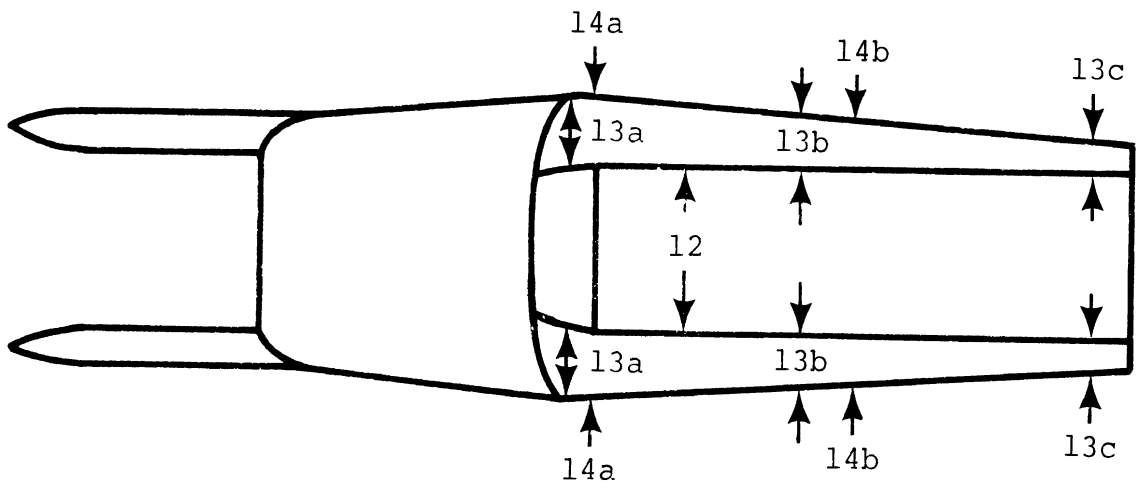
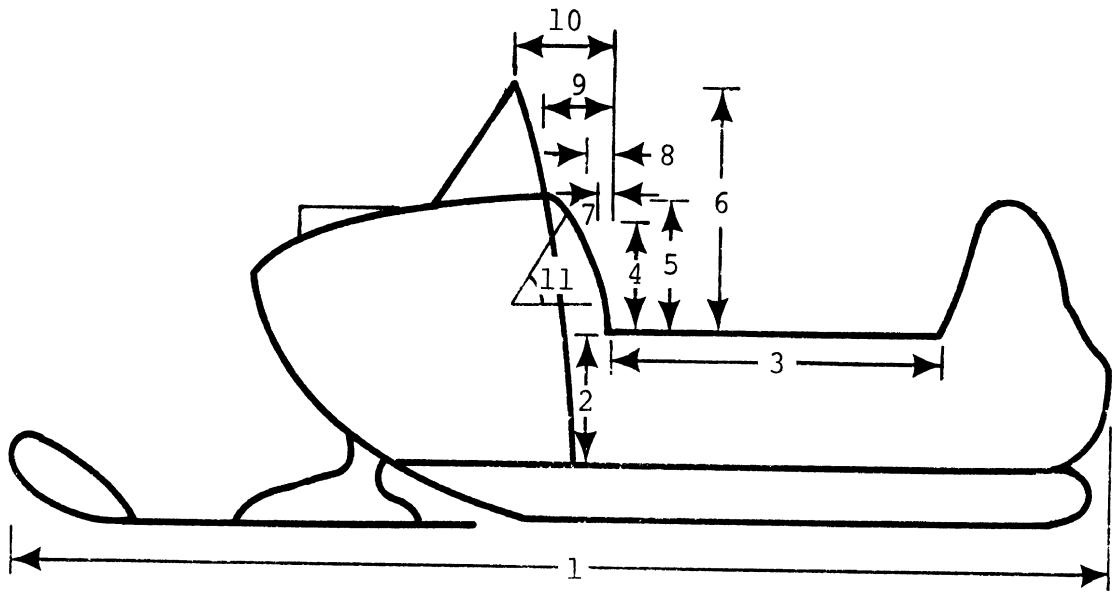
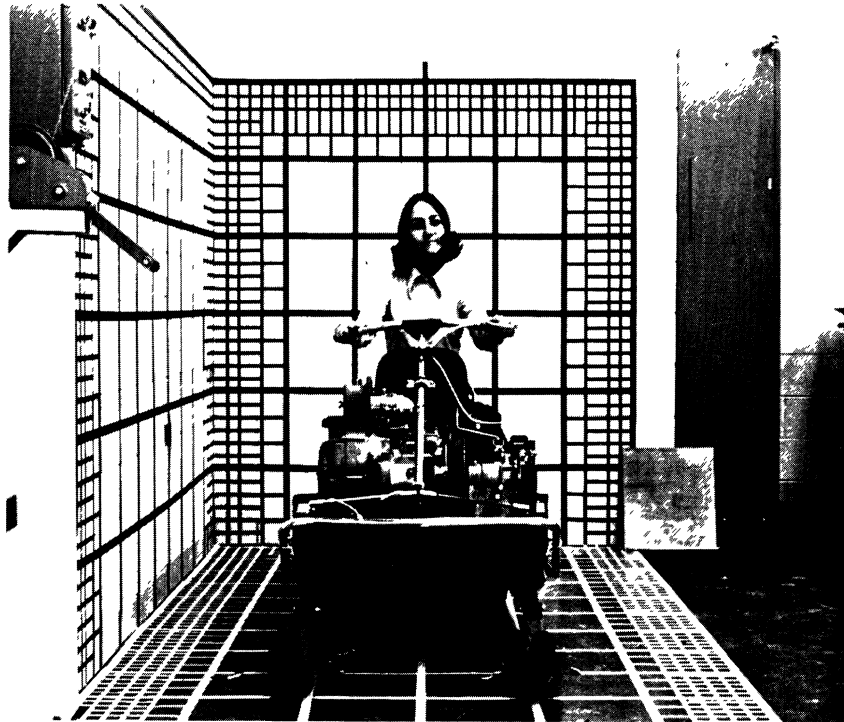
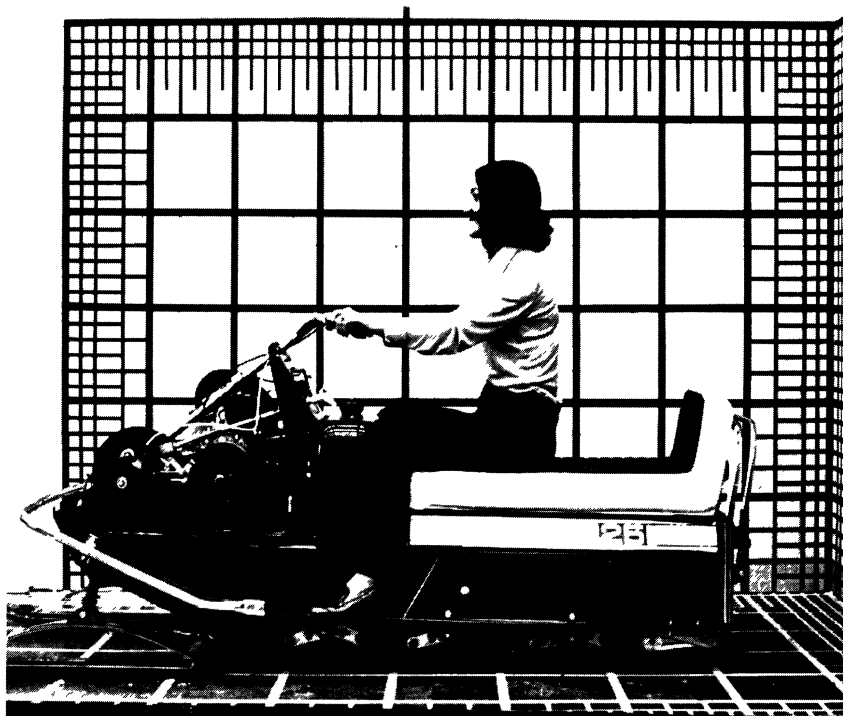


Figure 2. Physical dimensions of the snowmobile.

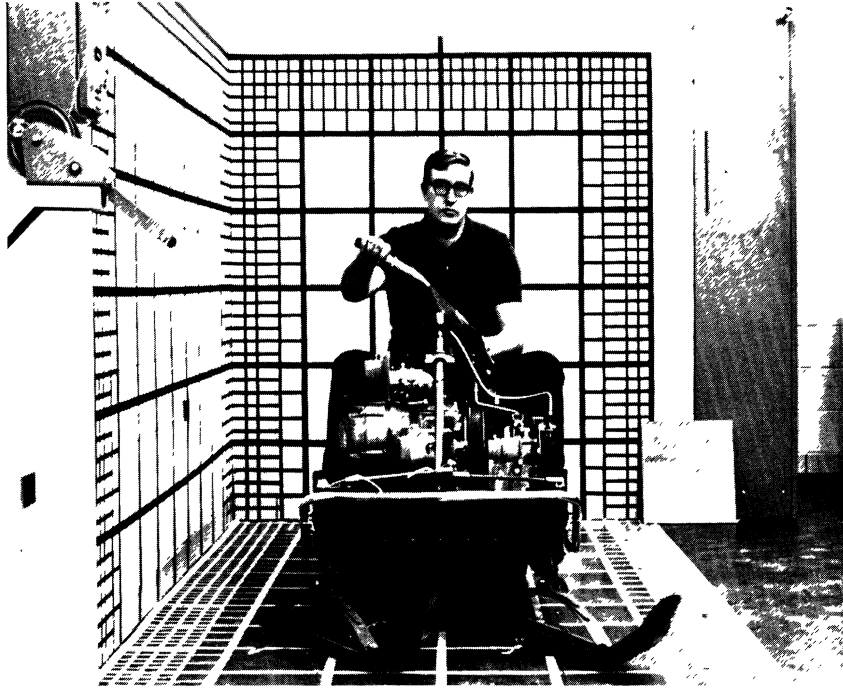


(Front View)

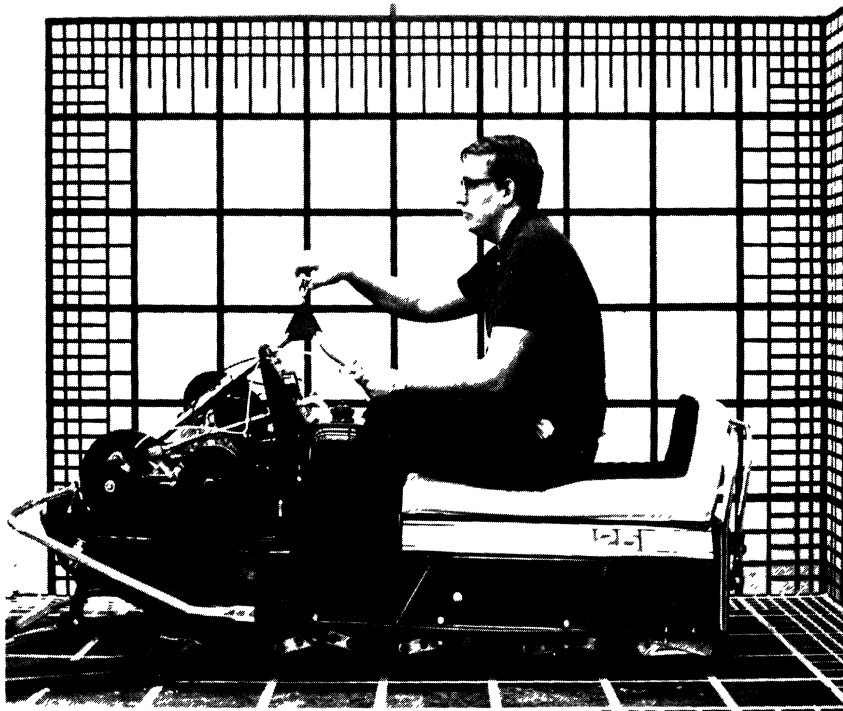


(Side View)

Figure 3. Female sitting alone, straight ahead position, Evinrude.

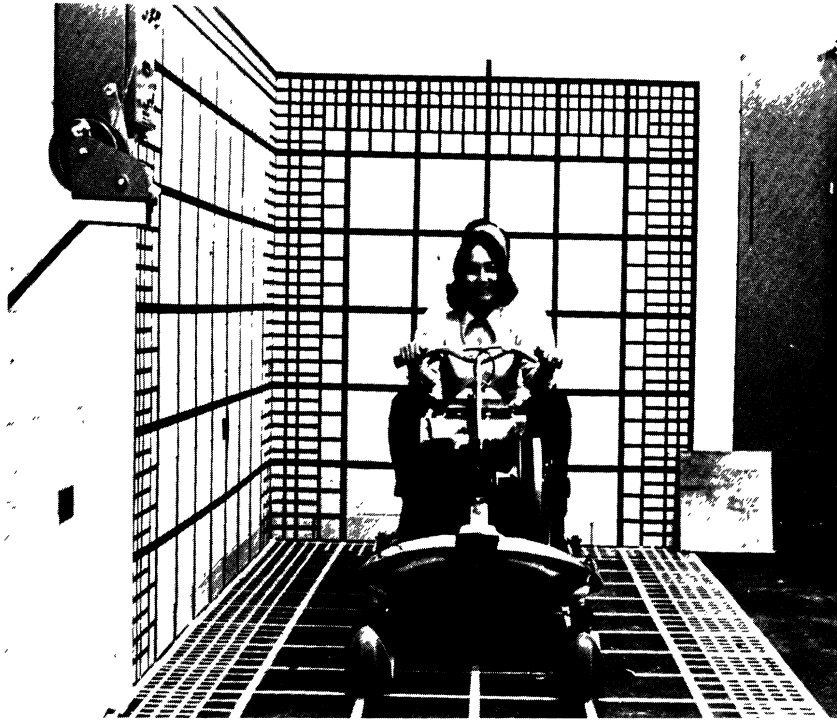


(Front View)

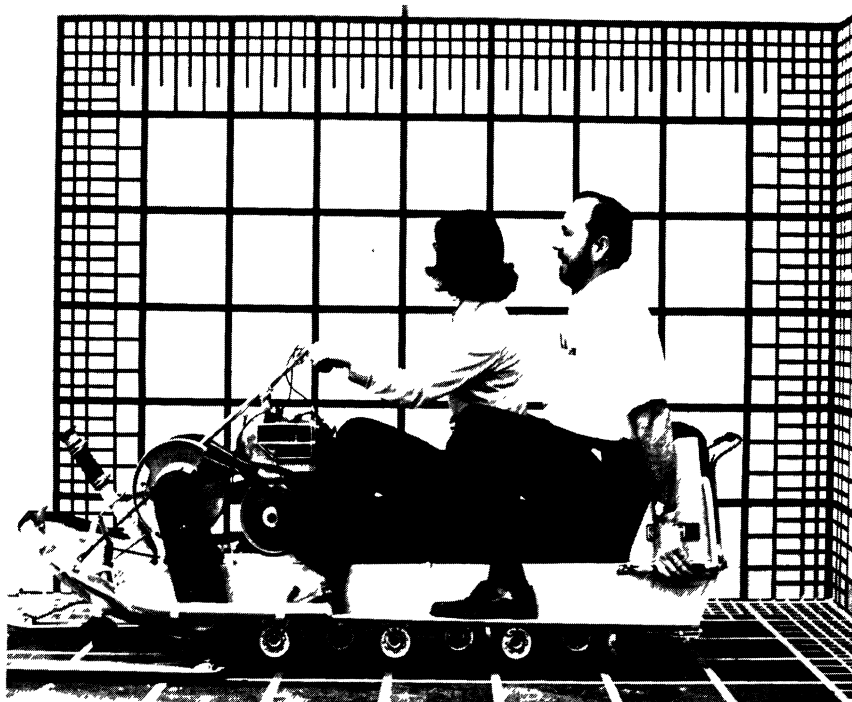


(Side View)

Figure 4. Tall male sitting alone, full left turn, Evinrude.

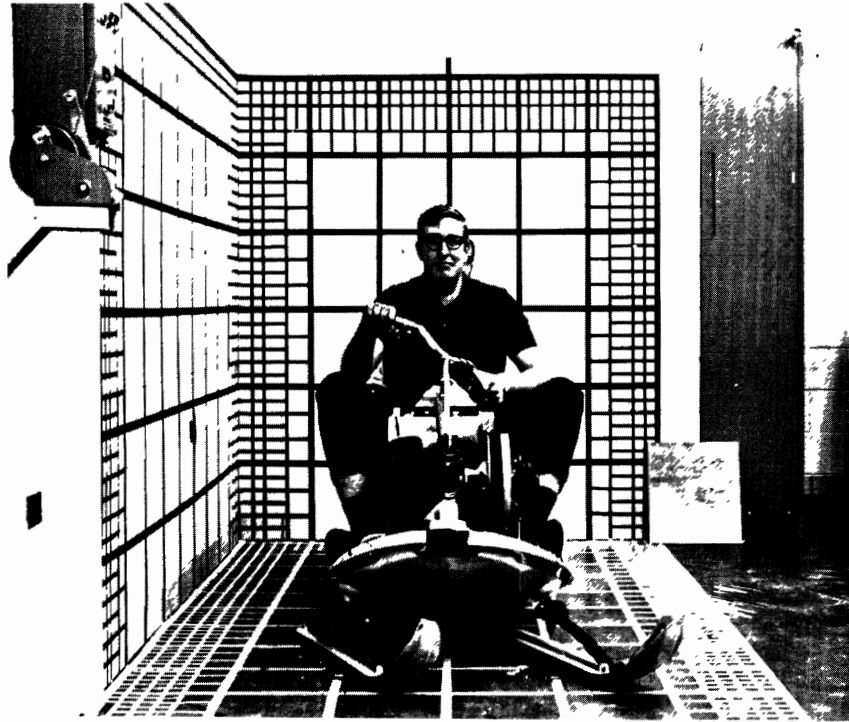


(Front View)

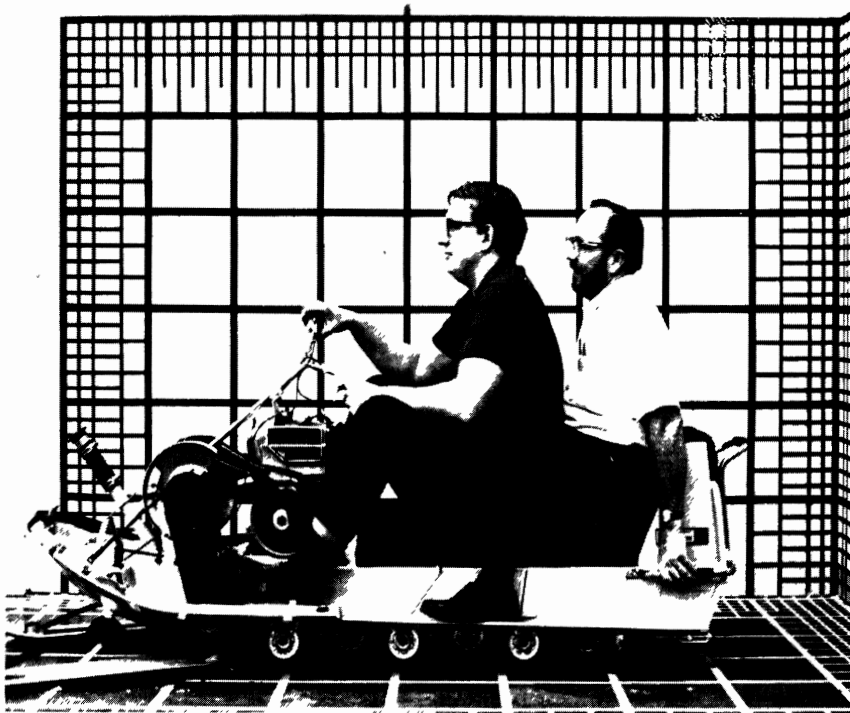


(Side View)

Figure 5. Female sitting with passenger, straight ahead position, Ski-Doo.

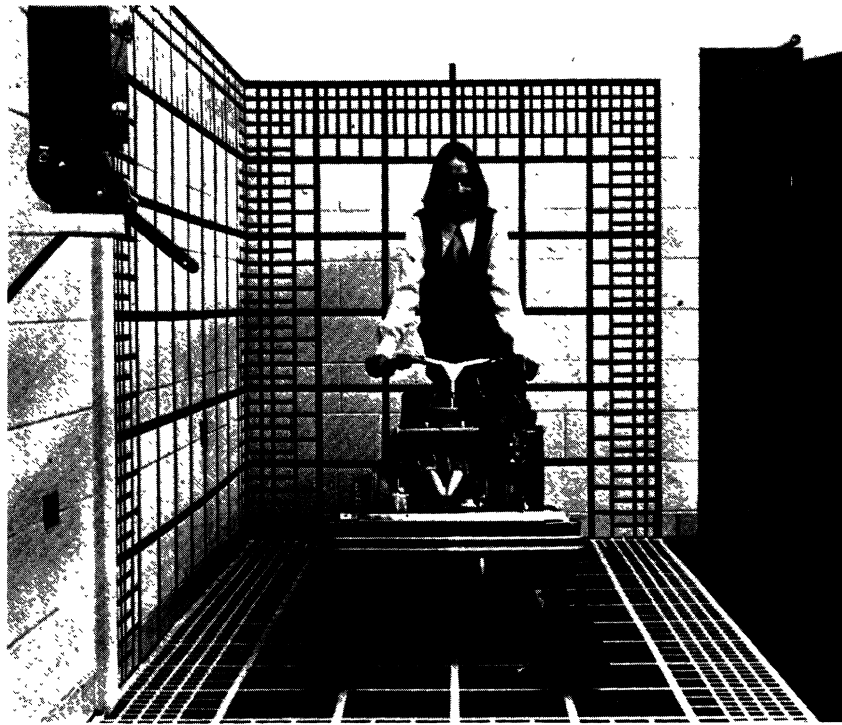


(Front View)



(Side View)

Figure 6. Tall male sitting with passenger, full left turn, Ski-Doo.

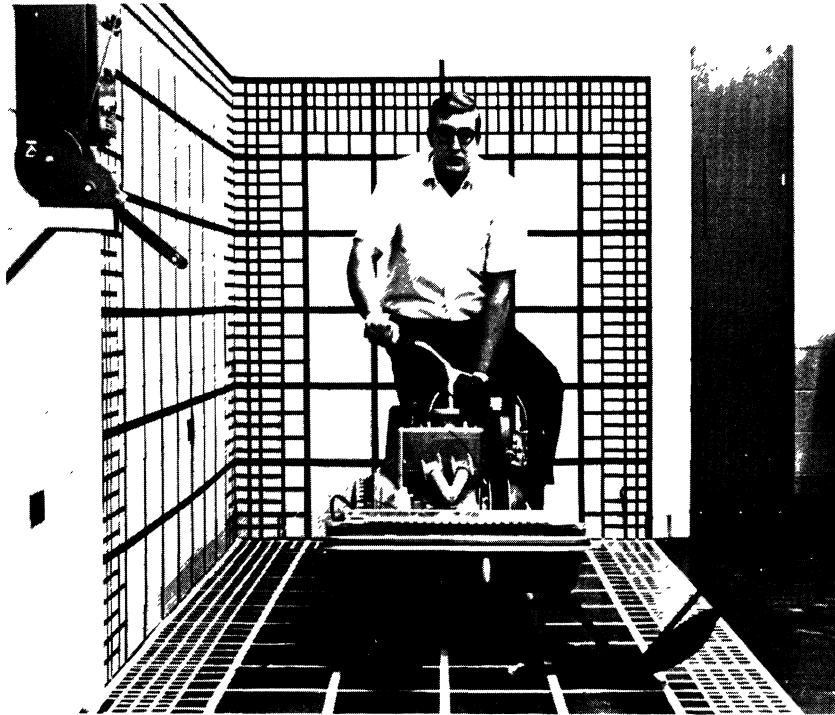


(Front View)



(Side View)

Figure 7. Female kneeling alone, straight ahead position, Arctic.



(Front View)



(Side View)

Figure 8. Tall male kneeling alone, full left turn, Arctic.

obtained of each subject in each position. The slides were then projected, and x, y, and z coordinates for ankle, knee, hip, shoulder, elbow, and wrist points were recorded directly from the reference grid. A computer program corrected these points for the parallax error involved in the photography, and then calculated knee, hip, shoulder, and elbow angles using the law of tangents. The resulting figures are intended for a comparison of angles only; limb lengths have been distorted by the transformation from three to two dimensions.

RESULTS

The angular measurement for the knee, hip, shoulder and elbow, for each subject, seated alone in a straight-ahead position, is shown for each of the snowmobiles in Table 5. The same information is shown graphically in Figure 9. This figure, and the five succeeding figures, show eye position for each of the subjects, and top of cowl and windshield. The floorboard and footrests are also shown. These data indicate that there are large differences between subjects. Some differences are due to body size; other differences would be expected because of the limited number of constraints. In an automobile the position adopted by the driver is influenced by the seat back, foot pedals, steering wheel, seat height and length, etc. The only snowmobile design variables that affect the operator's position are the handlebar, seat, and footrest position. Consequently, there are more sitting postures that can be adopted by the snowmobile operator.

Except on the Evinrude, the knee is considerably higher than the hip, in the sitting position, when the lower leg is upright. For all models tested eye height is approximately level with the top of the windshield. Shoulder height above the handlebars is greatest with the Evinrude and least with the Ski-Doo.

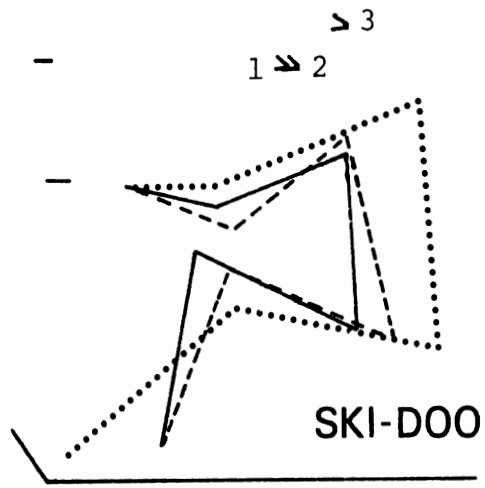
Table 6 and Figure 10 indicate angle measurements for a

TABLE 5. SUBJECTS SITTING ALONE,
STRAIGHT AHEAD POSITION
(Limb Angles In Degrees)

<u>Angle</u>	<u>Subject</u>	<u>Machine</u>			<u>Range</u>
		<u>Ski-Doc</u>	<u>Arctic</u>	<u>Evinrude</u>	
Knee	1	84	78	98	20
	2	89	82	95	13
	3	133	83	109	50
	Range	49	5	14	
Hip	1	62	69	79	17
	2	54	53	68	15
	3	75	56	63	19
	Range	21	16	16	
Shoulder	1	72	57	58	15
	2	66	53	47	19
	3	74	64	42	32
	Range	8	11	16	
Elbow	1	147	133	121	26
	2	123	108	106	17
	3	160	141	98	62
	Range	37	33	23	

full left turn, which can be achieved with a minimum of body movement. By extending the arm, a full turn can be made.

The variability of sitting positions for the operator is greatly reduced by placing a male of approximately mean stature on the vehicle as a passenger. Both the back and lower leg assume positions more vertical to the snowmobile base (Table 7 and Figure 11). The same type of reduction in variability occurs when a full turn is made with a passenger (Table 8 and Figure 12).



..... 99th percentile male
 ----- 49th percentile male
 _____ 59th percentile female

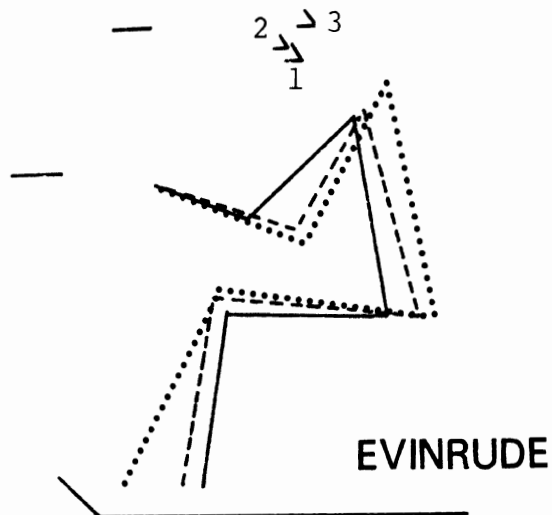
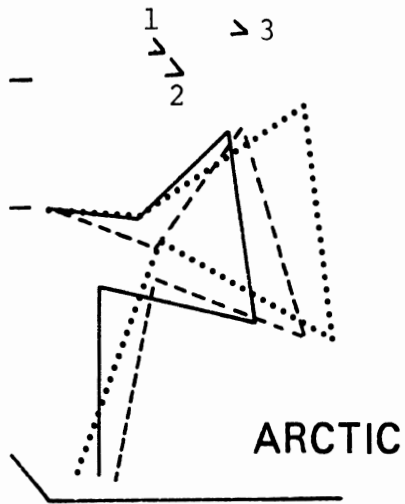
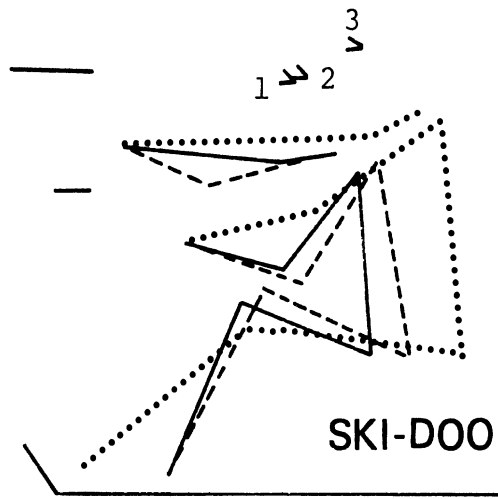


Figure 9. Subjects sitting alone, straight ahead position.

Tables 9 and 10 show angular measurements for the straight-ahead position and left turn position when the subject is kneeling. Figures are not presented with these tables because of the complexity of drawing and interpreting them. Greatest variance occurs in the knee angle, although it is considerable in the right elbow when subjects are kneeling and making a full left turn.

TABLE 6. SUBJECTS SITTING ALONE,
FULL LEFT TURN (Limb
Angles in Degrees)

Angle	Subject	Machine				Range			
		<u>Ski-Doo</u>	<u>Arctic</u>	<u>Evinrude</u>					
Knee	1	92	80	94	14				
	2	93	84	102	18				
	3	137	86	111	51				
	Range	45	6	17					
Hip	1	65	71	76	11				
	2	56	52	67	15				
	3	78	57	68	21				
	Range	22	19	9					
Shoulder		<u>Left/Right</u>		<u>Left/Right</u>		<u>Left/Right</u>		<u>Left/Right</u>	
	1	43	91	29	89	32	94	14	5
	2	44	100	22	100	34	86	22	14
	3	63	85	44	90	26	71	37	19
	Range	20	15	22	11	8	23		
Elbow	1	115	166	98	163	105	164	17	3
	2	109	145	77	146	101	151	32	6
	3	160	163	123	165	103	139	57	26
	Range	51	21	46	19	4	25		



..... 99th percentile male
 - - - - - 49th percentile male
 _____ 59th percentile female

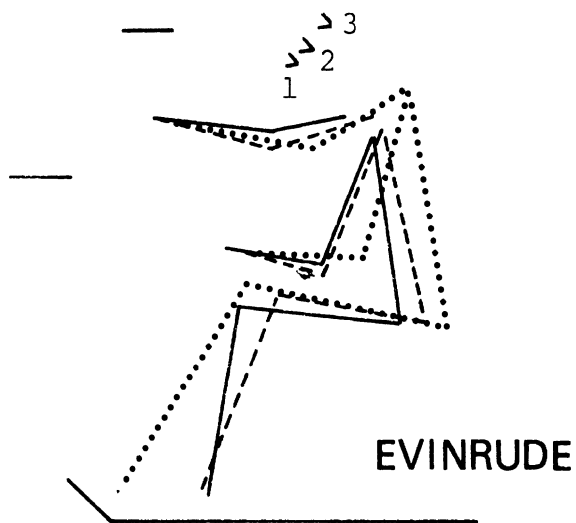
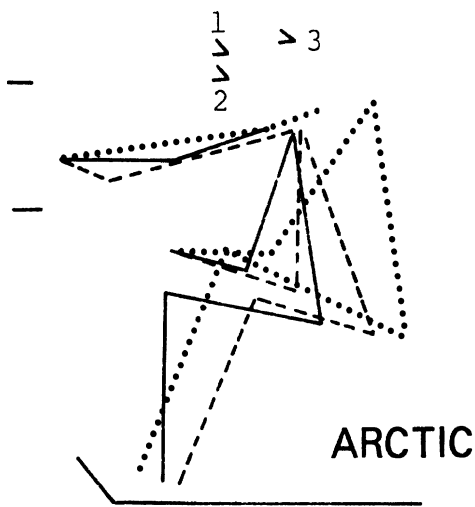
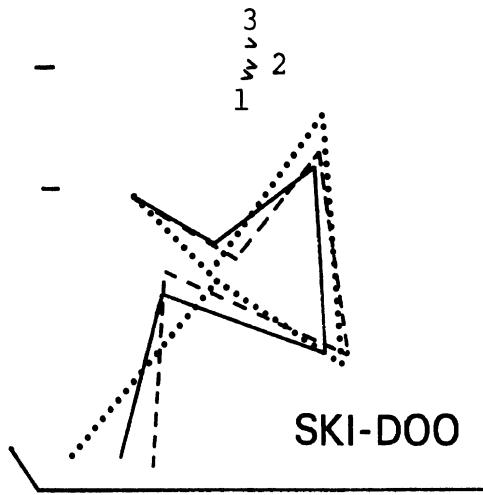


Figure 10. Subjects sitting alone, full left turn.

TABLE 7. SUBJECTS SITTING WITH PASSENGER,
 STRAIGHT AHEAD POSITION (Limb
 Angles in Degrees)

<u>Angle</u>	<u>Subject</u>	<u>Machine</u>			<u>Range</u>
		<u>Ski-Doo</u>	<u>Arctic</u>	<u>Evinrude</u>	
Knee	1	87	78	96	19
	2	70	75	89	19
	3	81	58	102	44
	Range	17	20	13	
Hip	1	68	70	78	10
	2	58	57	72	15
	3	55	55	61	6
	Range	13	15	17	
Shoulder	1	57	51	53	6
	2	48	45	42	6
	3	43	48	41	7
	Range	14	6	12	
Elbow	1	114	124	114	10
	2	101	99	110	11
	3	85	92	91	7
	Range	29	32	23	



..... 99th percentile male
 ----- 49th percentile male
 _____ 59th percentile female

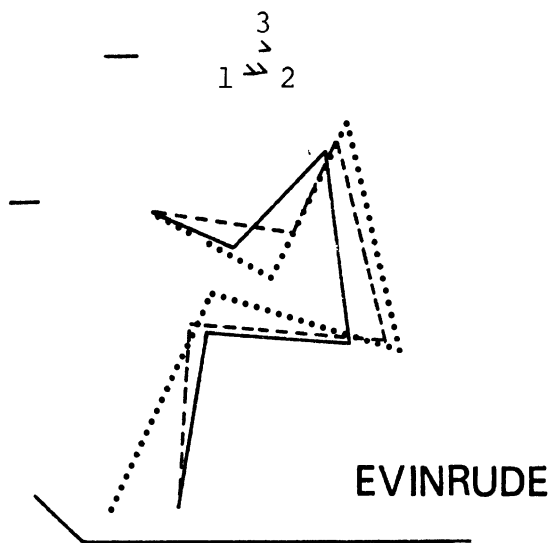
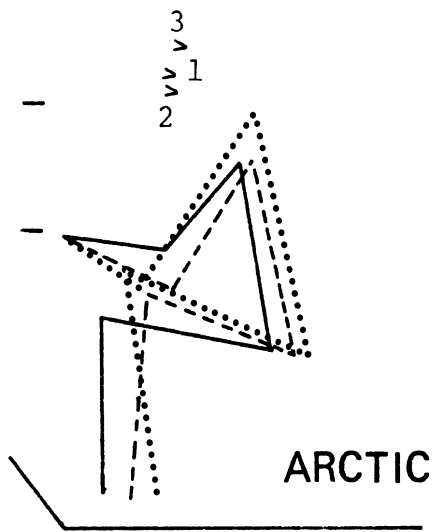
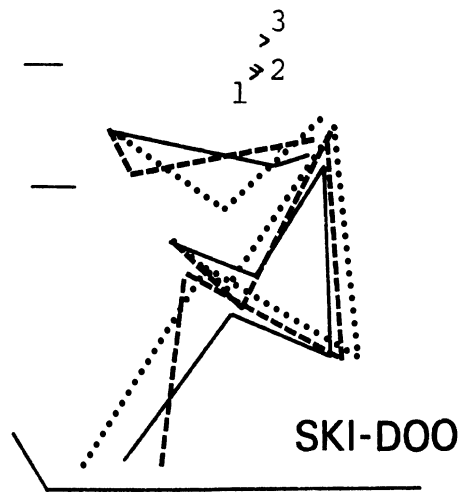


Figure 11. Subjects sitting with passenger, straight ahead position.

TABLE 8. SUBJECTS SITTING WITH PASSENGER,
FULL LEFT TURN (Limb Angles in
Degrees)

<u>Angle</u>	<u>Subject</u>	<u>Machine</u>				<u>Range</u>			
		<u>Ski-Doo</u>		<u>Arctic</u>			<u>Evinrude</u>		
Knee	1	88		79		98		9	
	2	73		75		98		25	
	3	83		46		105		59	
	Range	15		33		7			
Hip	1	66		69		85		19	
	2	60		54		80		26	
	3	55		62		63		8	
	Range	11		15		22			
Shoulder		<u>Left/Right</u>		<u>Left/Right</u>		<u>Left/Right</u>		<u>Left/Right</u>	
	1	37	80	31	86	26	84	11	6
	2	33	90	21	98	24	106	12	16
	3	42	60	25	46	35	66	17	20
	Range	9	30	6	52	11	40		
Elbow	1	105	153	98	165	112	160	14	12
	2	96	117	74	123	111	138	37	21
	3	87	110	111	137	107	80	24	57
	Range	18	43	37	42	5	80		



..... 99th percentile male
 ----- 49th percentile male
 ————— 59th percentile female

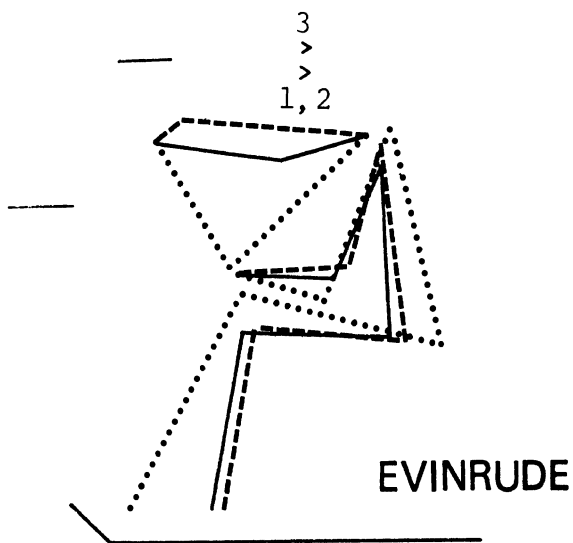
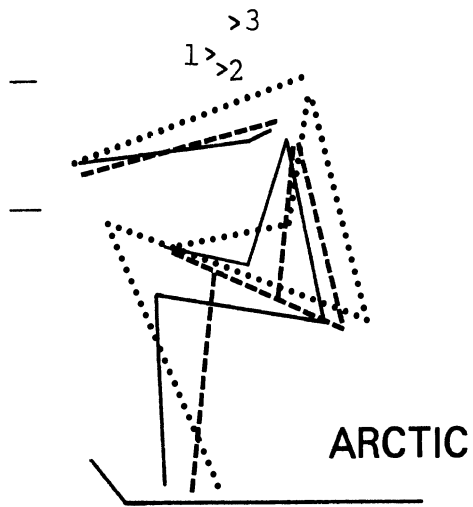


Figure 12. Subjects sitting with passenger, full left turn.

TABLE 9. SUBJECTS KNEELING, STRAIGHT AHEAD POSITION (Limb Angles in Degrees)

<u>Angle</u>	<u>Subject</u>	<u>Machine</u>						<u>Range</u>	
		<u>Ski-Doo</u>		<u>Arctic</u>		<u>Evinrude</u>		<u>Left/Right</u>	
		<u>Left/Right</u>	<u>Left/Right</u>	<u>Left/Right</u>	<u>Left/Right</u>	<u>Left/Right</u>	<u>Left/Right</u>		
Knee	1	126	85	124	95	163	91	39	10
	2	76	31	91	41	135	58	59	27
	3	102	52	96	55	130	37	34	18
	Range	50	54	33	54	33	54		
Hip	1	111	147	107	137	129	142	22	10
	2	92	110	95	112	123	149	31	39
	3	87	131	90	133	98	124	11	9
	Range	24	37	17	25	31	25		
Shoulder	1	46	58	47	58	42	57	5	1
	2	68	81	47	60	31	47	37	34
	3	41	53	37	45	37	45	4	8
	Range	27	28	10	15	11	12		
Elbow	1	164	168	170	168	169	168	6	0
	2	165	150	155	151	163	163	10	13
	3	165	152	162	157	159	156	6	5
	Range	1	18	15	17	10	12		

TABLE 10. SUBJECTS KNEELING, FULL
LEFT TURN (Limb Angles
in Degrees)

<u>Angle</u>	<u>Subject</u>	<u>Machine</u>						<u>Range</u>	
		<u>Ski-Doo</u>		<u>Arctic</u>		<u>Evinrude</u>			
		<u>Left/Right</u>	<u>Left/Right</u>	<u>Left/Right</u>	<u>Left/Right</u>	<u>Left/Right</u>	<u>Left/Right</u>	<u>Left/Right</u>	<u>Left/Right</u>
Knee	1	128	89	132	94	175	89	47	5
	2	77	39	98	52	133	45	56	13
	3	104	58	100	54	132	44	32	14
	Range	51	50	34	42	43	45		
Hip	1	96	140	96	128	129	142	33	14
	2	87	119	101	127	101	127	14	8
	3	78	136	82	125	84	114	6	22
	Range	18	21	19	3	45	28		
Shoulder	1	44	72	48	88	43	74	4	16
	2	52	88	33	83	26	80	26	8
	3	36	62	28	61	41	59	13	3
	Range	16	26	20	27	17	21		
Elbow	1	171	172	174	168	175	161	4	4
	2	164	159	155	154	151	106	13	53
	3	167	124	162	138	166	111	5	27
	Range	7	48	19	30	24	55		

DISCUSSION

From an anthropometric and human factors standpoint the snowmobile should be designed for maximum comfort and safety for the conditions in which it is used. Table 4 indicates that snowmobiles differ considerably in physical dimensions that affect the operator's posture. A broader range would not only be expected but necessary when compared with an automobile because (1) snowmobile drivers are not restricted by licensing, (2) all controls are operated with the hands so the feet need not remain in one location, (3) body motion must be used to help maintain stability, (4) various positions such as sitting and kneeling are assumed depending upon the terrain and snow conditions, and (5) riders need to be able to extricate themselves rapidly in the event of a turnover.

The cowling provides protection for the body from objects the snowmobile may strike from straight on. The range of cowling height for the three vehicles examined was from 22.5 inches for the Arctic to 29.75 inches for the Evinrude. The Evinrude provides 32 percent more coverage than the Arctic and consequently may provide better protection.

The height of the seat is an important consideration because in going over hills or bumps it is necessary to post, as in horseback riding (i.e., shift one's weight off the posterior onto the legs and feet). Failure to post has resulted in spinal injuries. It is easiest to raise one's posterior if the seat cushion is at least as high as the popliteal height. A minimum height of 13.6 inches is recommended (Damon, Stoudt, McFarland, 1966) to accommodate 5th percentile females. To accommodate the 1st through 99th percentile, females and males, a seat height range of approximately 13 to 21 inches would be necessary. Two of the vehicles examined had seat heights of about 14 inches. One vehicle had a seat height of 10 inches, which makes posting difficult for

the adult rider and is outside the recommended limits.

Footrest widths for the center and front of the footrest were 3.5 to 6.5 inches. The 95th percentile foot breadth for men is 4.3 inches and 3.9 inches for women. Depending on the type of boot worn, 0.3 to 1.2 inches should be added. Wider footrest areas on most vehicles should be beneficial. Several manufacturers slant the footrest area with the high edge on the outside. This makes it easier to keep one's feet in place. Several snowmobiles have bars in the footrest area to provide structural support for the footrest. If these supports do not catch the boot and hinder extrication they are satisfactory, but catching the boot could result in injury.

Seat length appears adequate for two adults. Handlebar grip diameters around 1.5 inches are considered maximum for the ungloved hand. This is the average for the vehicles tested. Hand levers are used for brake and throttle control. The brake lever should be long enough to allow the weaker operators to obtain maximum brake torque. Several of the vehicles in production today have brake levers which do not permit all of the fingers to be placed on the lever, and consequently reduce the force that can be applied by the operator. Gloved-hand operation should be considered in the design of these controls as well as other controls such as the ignition switch, choke and light switch, and parts that can be conveniently maintained or serviced in the field.

The extent of handlebar rotation for the vehicles examined ranged from 80° to 140°. This is an unexpectedly large range with probable important consequences on vehicle control. The angle of handlebar rotation is probably not important unless a bump is hit and the vehicle turns sharply. Then, at high speeds, the resulting large, inadvertent steer angle would almost certainly cause the vehicle to overturn if no side slipping of the skis occurred. On the other hand, at low speeds the greater rotation angle might be desirable for greater maneuverability.

Most of the snowmobiles provide grab bars for the passenger. The bars are generally located behind and below the passenger. Such a location is hard to reach, uncomfortable and fatiguing to use, and, in addition, does not appear to provide satisfactory restraint.

Some vehicles permit the legs to be placed underneath the cowl whereas others do not. As long as it does not become necessary to free oneself from the vehicle, it is expected that cowl protection would be desirable. However, in the event of an overturn, it might be more desirable to get off the vehicle before it overturns completely since most machines provide no rollover protection. If the vehicle overturns and the riders are not able to free themselves during the mishap, it is possible for the rider to be struck by the edge of the footrest or some other part of the machine, and for the feet to become entangled in the power track.

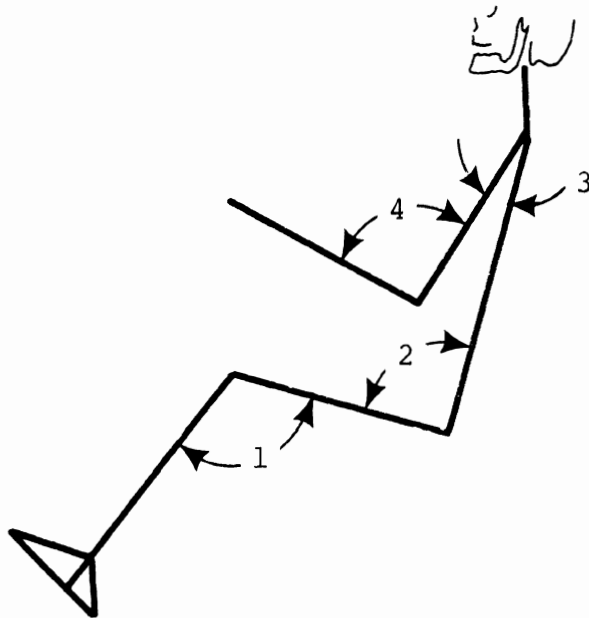
The most dangerous aspect of the snowmobile may be the low windshield, which provides little protection to the neck and face in collisions with fences, ropes or guy wires. Figures 9-12 indicate that the 50th percentile snowmobiler has eye height about equal to the top of the windshield. Since the windshield may be trimmed with a metal strip, obstruction of visions is maximum. In addition, the windshields are designed to be flexible so they do not shatter into the face or body of the driver. Consequently, protection from foreign objects is minimal.

Photographs of subjects on the snowmobiles indicate that, because of the low sitting position required on some of the models, knees and elbows are close to each other and compete for the same space. This may restrict control movement.

The angular measurements for the knee, hip, shoulder, and elbow obtained in this study can be compared with the comfort angles reported by Rebiffé (1966) which are shown in Table 11.

TABLE 11. LIMB JOINT COMFORT ANGLES (FROM REBIFFÉ, 1966)

- 1. Knee: $95^{\circ} - 135^{\circ}$
- 2. Hip: $95^{\circ} - 120^{\circ}$
- 3. Shoulder: $10^{\circ} - 45^{\circ}$
- 4. Elbow: $80^{\circ} - 120^{\circ}$



Figures 13-16 show the range of limb angles for the three drivers in each of the six conditions and on each of the snowmobiles. A comfort angle range of from 95° to 135° is recommended by Rebiffé for the knee. Figure 13 indicates that the knee angles on the snowmobiles are usually less than 95°. Only the Evinrude permitted acceptable angles under all nonkneeling conditions. Failure to meet the acceptable angle range was due primarily to low seat placement.

Except in the kneeling position, all of the hip angles were less than desirable (Figure 14). This was primarily due to seat height being too low.

Due to handlebar location and the absence of a seat back drivers would not necessarily be expected to have shoulder angles similar to those reported by Rebiffé for car drivers. As Figure 15 shows, shoulder angles were usually found to be greater than those recommended.

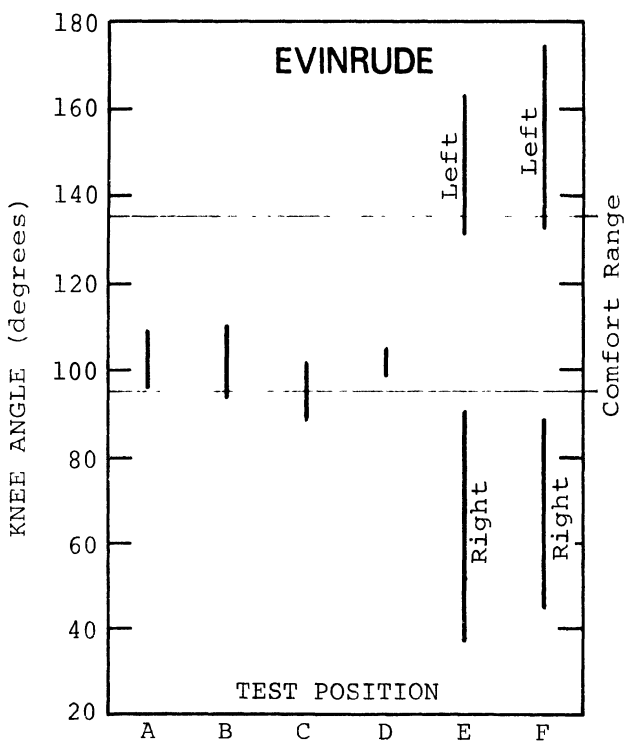
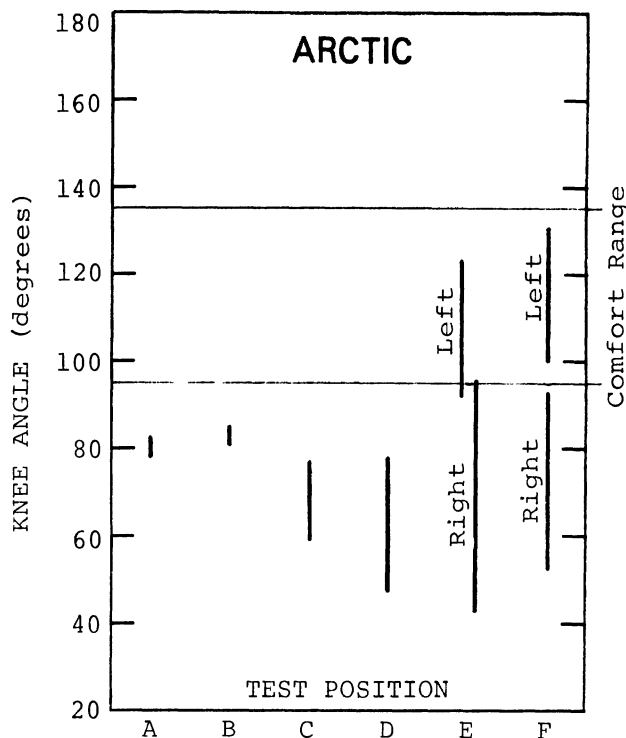
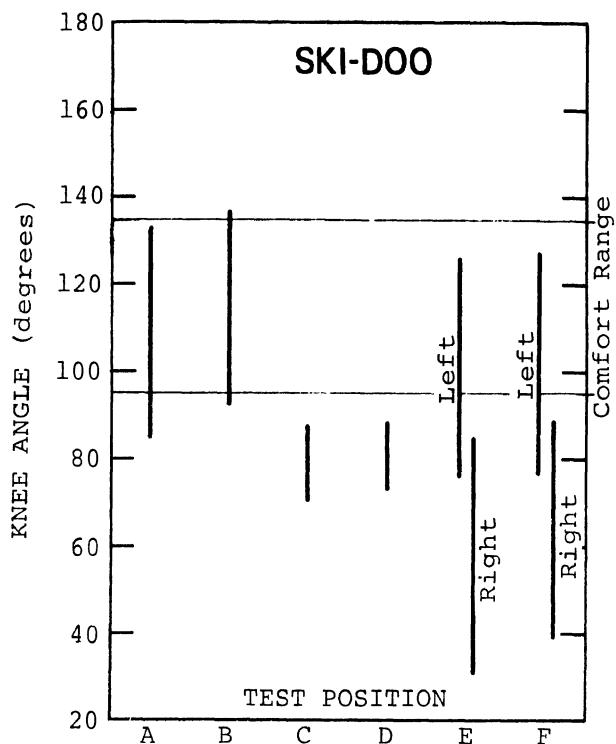
The elbow angles, shown in Figure 16, although on the high side, are fairly good for the sitting position but bad for the kneeling position.

In a comparison of comfort angles obtained in an automobile and on snowmobiles, the Evinrude provides more angles within the comfort range than the Ski-Doo or Arctic.

Although the comfort angle ranges reported by Rebiffé need to be extended in order to apply to the snowmobile, the initial analysis shows that snowmobiles do not provide a work area which is conducive to comfort.

RECOMMENDATIONS

The present study has revealed numerous areas in which human factors considerations would result in a safer and more comfortable vehicle. As the snowmobile becomes increasingly popular these needs will increase. While the snowmobile is



- A Alone, Straight Ahead
- B Alone, Turned
- C Passenger, Straight
- D Passenger, Turned
- E Kneeling, Straight
- F Kneeling, Turned

Figure 13. Knee angle range of subjects in each test position.

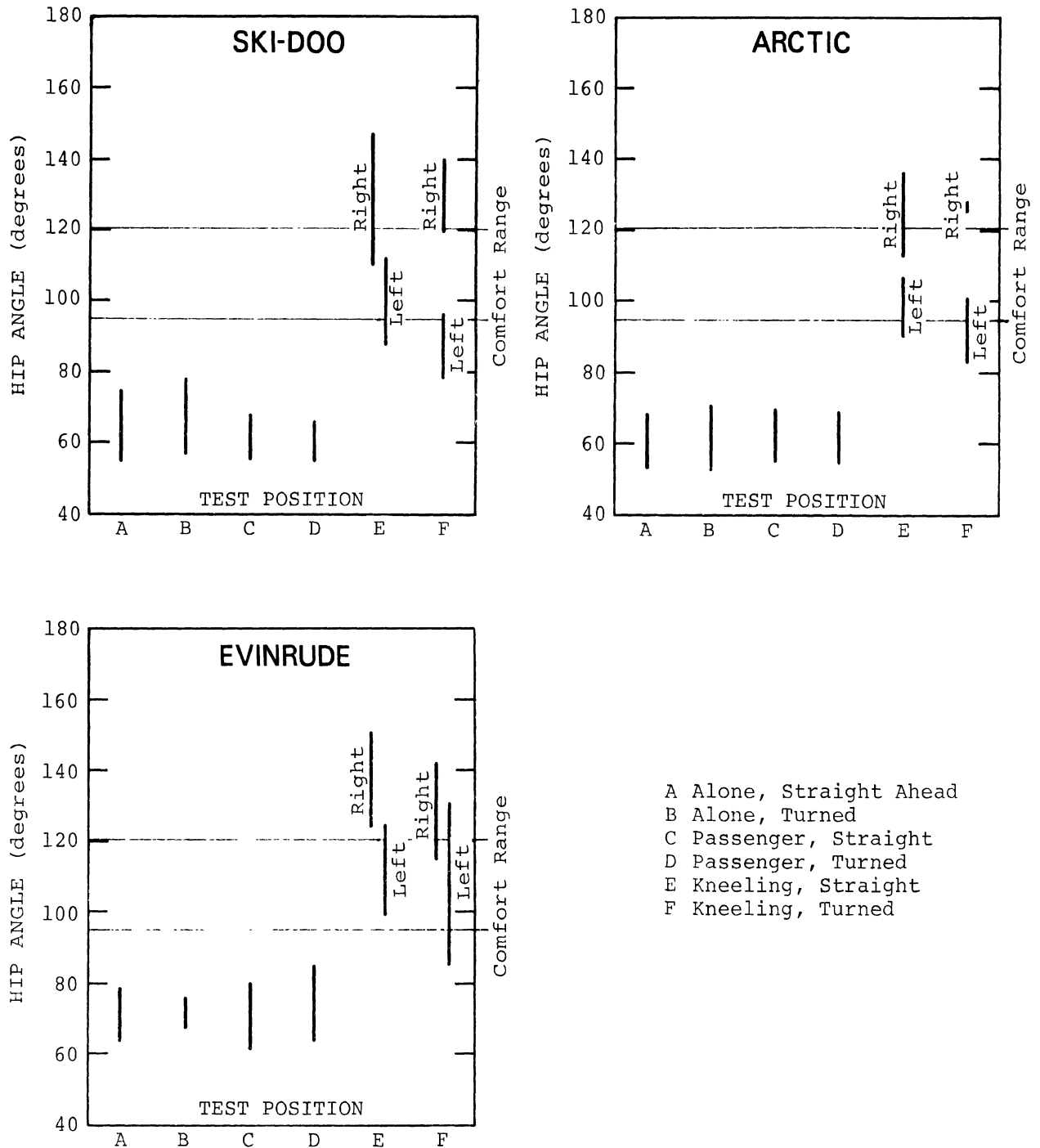
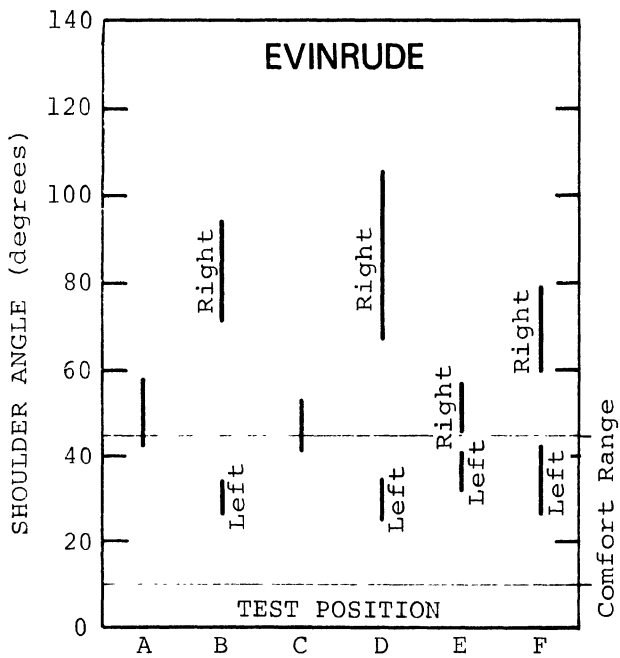
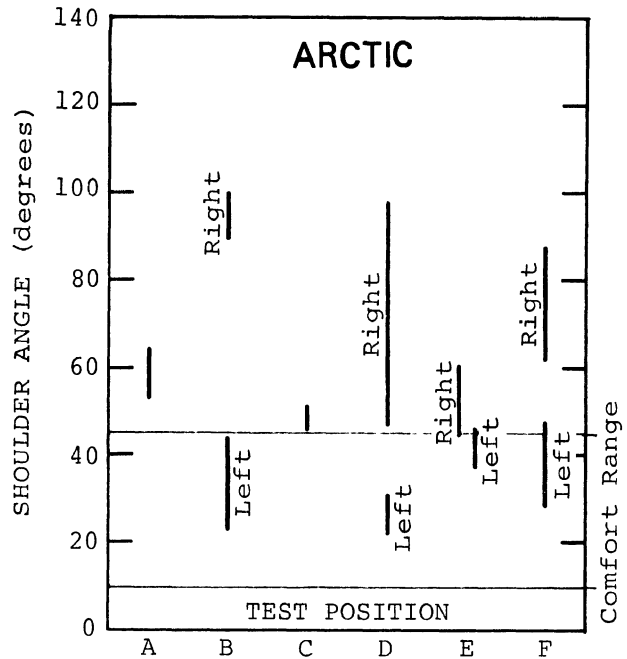
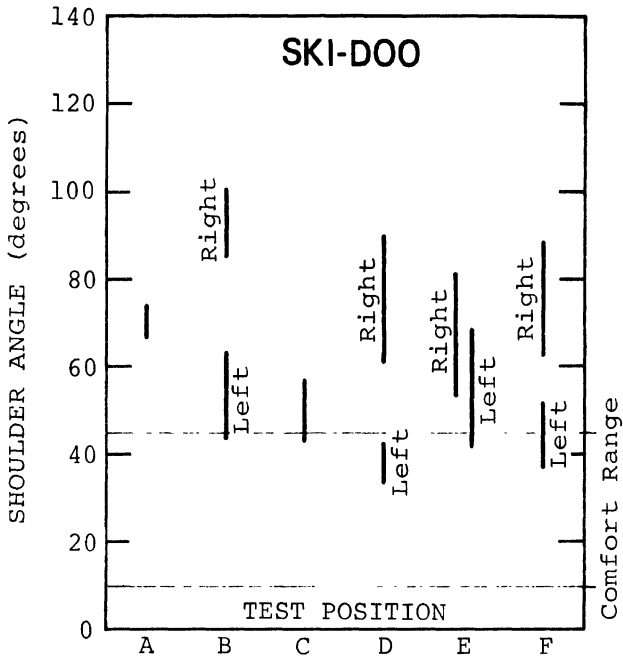
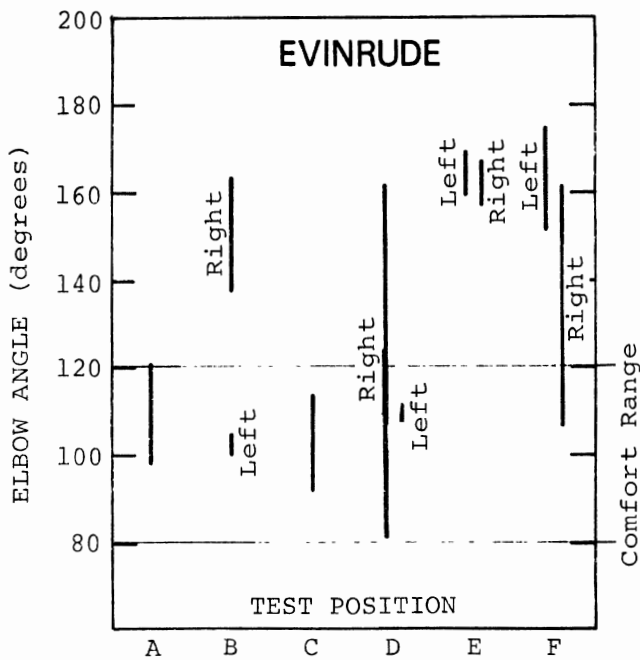
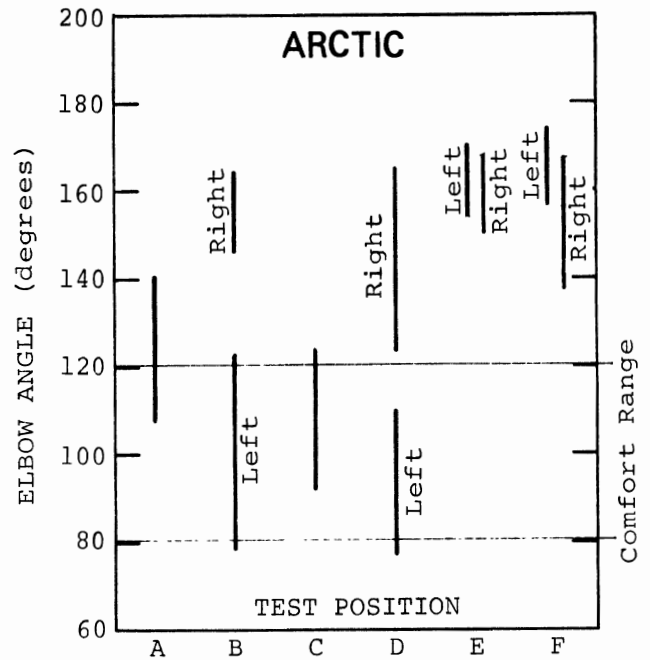
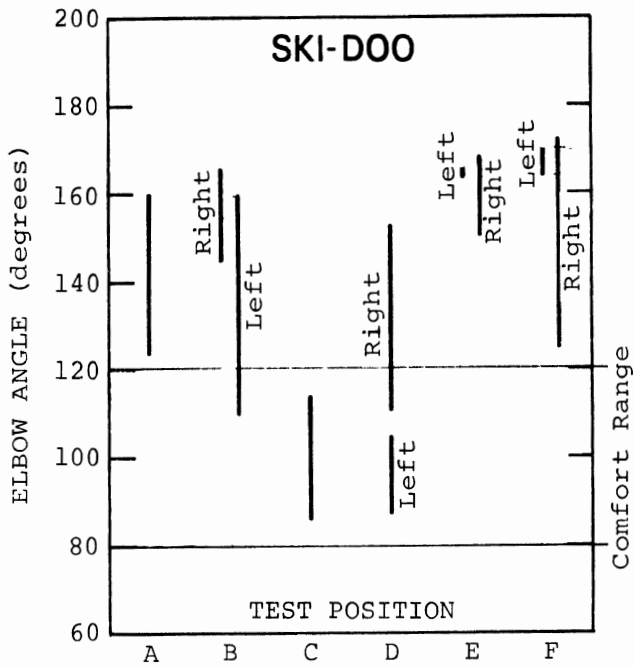


Figure 14. Hip angle range of subjects in each test position.



- A Alone, Straight Ahead
- B Alone, Turned
- C Passenger, Straight
- D Passenger, Turned
- E Kneeling, Straight
- F Kneeling, Turned

Figure 15. Shoulder angle range of subjects in each test position.



- A Alone, Straight Ahead
- B Alone, Turned
- C Passenger, Straight
- D Passenger, Turned
- E Kneeling, Straight
- F Kneeling, Turned

Figure 16. Elbow angle range of subjects in each test position.

in the infancy of its development the industry should conduct a human factors engineering analysis and incorporate the recommendations into snowmobile design early in development, rather than after years of production and rigidification of design. It is well known that comfort and safety can be attractive from a design and a sales standpoint.

The current study was conducted under static conditions by experimenters and subjects who were relatively unfamiliar with snowmobiles. Despite this lack of knowledge, or perhaps because of it, some areas for improvement were found. Specific recommendations follow.

WINDSHIELDS

A study should be conducted to determine optimal windshield structural design, dimensions, and placement. Protection should be provided for at least the 95th percentile male in the kneeling position, but because this height is about 50 inches, wind resistance would be very high if the windshield were extended to this height. A seat-to-eye height of 34 inches will protect the 95th percentile male in the sitting position. It does not seem unreasonable to design the cowl and windshield to provide this protection, and extend the windshield frame or a rollbar up at least another 17 inches to provide protection when in the kneeling position. From a safety standpoint, the present windshield material, which does not shatter, appears desirable, but a sturdy, padded, steel rim around the windshield which could withstand high forces without breaking or tearing apart would protect riders from unseen wires and branches as well as other objects. This rim should be high enough and narrow so that it does not block the driver's view more than absolutely necessary. The distance between windshield and rider determines how well he will be shielded from the wind. Size of the

windshield will be determined in part by its placement. These considerations also hinge upon rider kinematics in collisions about which there is little known for snowmobiles.

SEATS

Seat height is important for comfort and safety. Many spinal injuries have been sustained by riders who remained seated when jumping their snowmobiles. Ideally, the seat should be designed to absorb the estimated 8.5 g of a jump (McLay and Chism, 1969) so that the inexperienced and uninformed rider will not be injured. If such a passive system cannot be designed, however (and even if it can be), adjustable seat heights would be desirable, both for the driver and the passenger. This would permit easier posting and greater comfort and safety. A durable warning label about the consequences of failing to post should be permanently attached to the dashboard in an easy-to-read location.

FOOTRESTS

The inward slant of footrests is a commendable idea which should be incorporated on all vehicles. The use of structural support bars should be studied to find out if they interfere with removing the foot. If they do not, these bars might be designed to provide rollover protection for the leg. To accommodate the booted foot a minimum footrest width of about 6 inches for both driver and passenger would be desirable.

Placing the feet under or behind the cowl would not only provide protection from physical objects but from wind chill as well. Such a design would seem to be desirable unless one wished to free oneself from the vehicle and were prevented from doing so by the cowl and engine.

HANDLEBARS

Handlebars should be positioned so that the arms do not get in the way of the legs or vice versa. This might require that

handlebars be adjustable in height. The brake and throttle levers need further consideration because a short brake lever does not give a good mechanical advantage and a thumb-operated throttle may be uncomfortable, especially when wearing gloves.

Studies should be conducted to determine the desirable maximum steering angle. It may be found useful to utilize a form of steering damping (i.e., viscous damping) to reduce the possibility that large steer angles are inadvertently used at high speeds.

The handlebars provide stability for the driver whereas the passenger must use grab bars which are located at the rear of the seat. This location is awkward to reach and does not provide sufficient stability. Hand grips or a seat strap in front of the passenger could provide such stability.

BODY ANGLES

Figures 9-12 have indicated a variety of sitting and kneeling positions dependent upon body anthropometrics, subject preferences, and vehicle design. A comparison of body angles with angles of comfort, Figures 12-16, have indicated that present design does not provide for rider comfort.

Windshields, seats, footrests, and handlebars can all be designed to provide comfort as well as safety. The first step in a further snowmobile study would be to determine angles of comfort for the various positions necessary in snowmobile operation and the design necessary for maximum safety. The work area can then be designed to meet these criteria.

OTHER FACTORS

This study has been concerned primarily with the anthropometrics of snowmobile design which can contribute to safety and comfort. There are other areas which also warrant human factors considerations. Among these are the design of the

vehicle for ease of maintenance; lighting and marking for night vision and identification; licensing of vehicles and drivers; signing of trails; and safety equipment such as a first aid kit, vehicle repair kit, and signaling devices to be used when lost or stranded.

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