

# School Bus Safety Research: Physical Capabilities of Young Children



**MURRAY STATE**  
UNIVERSITY

Jesse D. Jones College of Science,  
Engineering and Technology



**AUBURN**  
UNIVERSITY

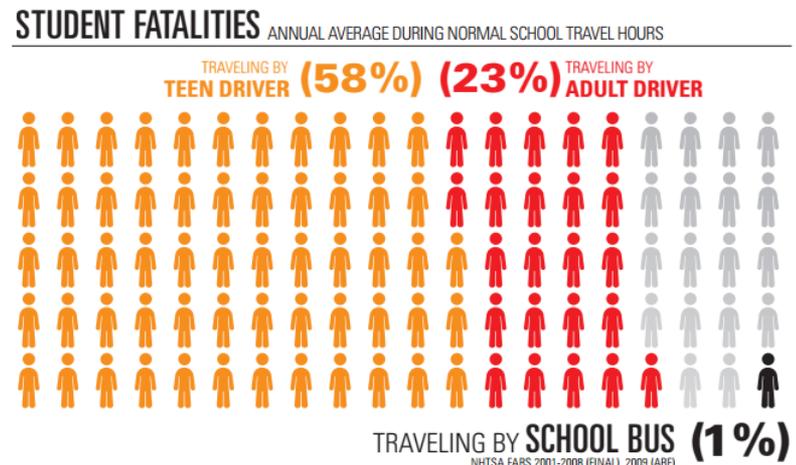
SAMUEL GINN  
COLLEGE OF ENGINEERING

Yousif 'Joe' Abulhassan, PhD, AEP  
Assistant Professor, Occupational Safety & Health  
Murray State University, KY

Jerry Davis, PhD, CSP, CPE  
Professor, Industrial and Systems Engineering  
Auburn University, AL

# Motivation

- ~23.5 million children regularly ride school buses in the United States.
- ~26,000 accidents involving school buses are reported annually.
- Despite this, school buses remain among the safest modes of transportation.
- This research represents an effort to further improve school bus safety.



# Background

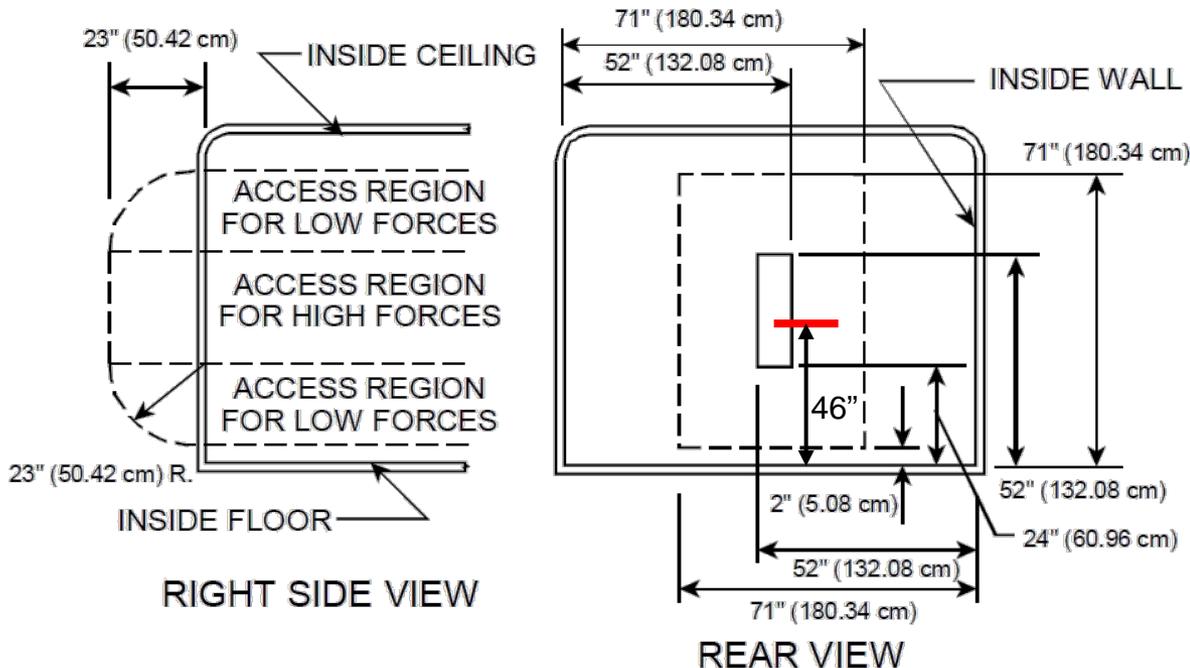
- There are some concerns regarding opening emergency exits and keeping them open when the bus is not in the upright orientation.
  - Safety Recommendation A-00-072. National Transportation Safety Board. 2000
- There are also concerns with respect to the operability of the emergency exits after a rollover accident and the impact of inoperable exits on emergency evacuations.
  - Federal Register Proposed Rules. NHTSA. 2014



- Defines the size and force requirements to operate emergency exits on school buses in the upright orientation.
- Force requirements are a function of the location of the emergency exit operating mechanism.
  - High force regions correspond to regions in which an able-bodied person can exert maximum force (Relatively close to shoulder height of an average adult male) [Pollard and Markos, 2009]
- Maximum Permissible Force:
  - High Force Regions: 178 Newton's (40 pounds)
  - Low Force Regions: 89 Newton's (20 pounds)

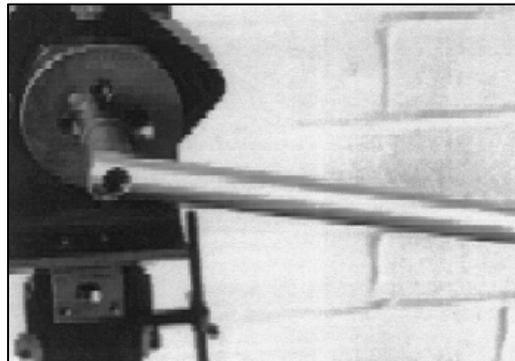
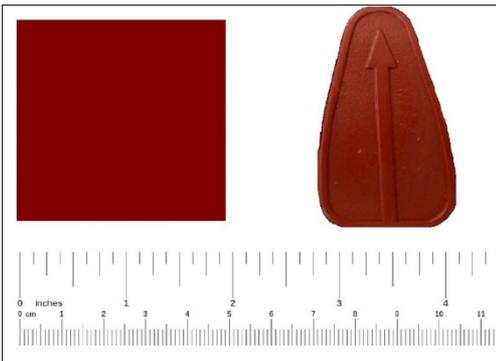
# Rear Emergency Door Operating Mechanism

- The motion required to operate the rear emergency door depends on the orientation of the school bus.



# Strength of Children

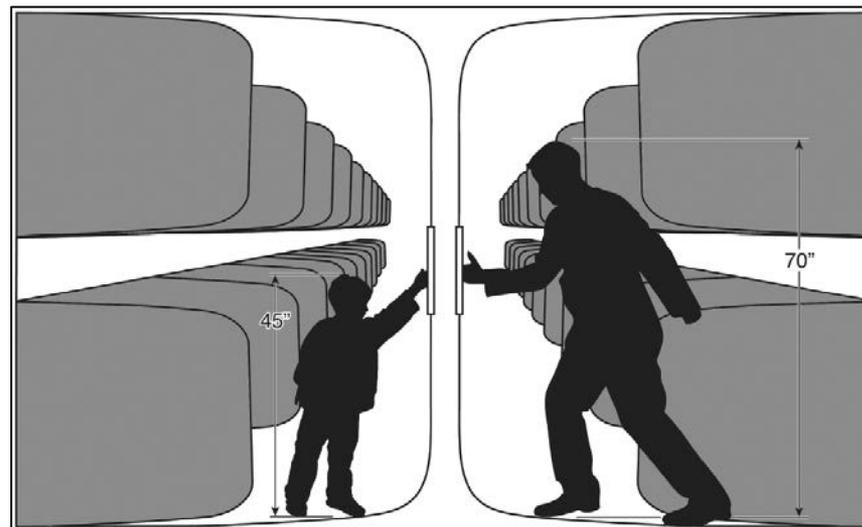
- Opening the emergency exit is a significant portion of total egress time [Sliepcevich, C.M., et al., 1972].
- Several strength measurement studies exist, however it is hard to apply them directly to the design of emergency escape devices [Sliepcevich, C.M., et. al., 1972]:
  - Standardized Postures
  - Geometries of Measurement Equipment



# Height of Children

- *“Anthropometric reference data for children and adults: United states, 2007-2010”* [Fryar et al., 2012]

Age	Gender	No.	Mean	SD	5th Percentile	95th Percentile
5	Male	205	44.8	0.22	41.0	47.9 (*90th)
7	Male	215	49.4	0.17	46.1	53.8
10	Male	211	59.0	0.24	54.7	64.2
5	Female	177	44.3	0.18	41.0	48.1
7	Female	207	49.1	0.21	44.7	52.8
10	Female	183	56.9	0.21	52.7	61.2



# Problem Statement

- FMVSS No. 217 does not consider the physical capabilities of the youngest group of children riding school buses.
- No standard egress time has been established to evaluate the effectiveness of emergency exits on school buses.
- Are children capable of evacuating a school bus in the upright and rolled-over orientations without adult intervention?
  - Stature and Physical Capabilities
  - Cognitive capabilities to read and follow instructions

# School Bus Mock-up

- Blue Bird Vision
  - Model year: 2013
  - Seating capacity: up to 78 passengers



# Study 1: Evacuation Through the Rear Emergency Door

- Measure the maximum force that could be exerted on the rear emergency door handle by children in K-2.
- Determine if K-2 children are able to unlatch the rear emergency exit in both upright and rolled over orientations.
- Determine if K-2 children are able to self-extricate (individually) through the rear emergency exit in a rolled over orientation.

# Hypotheses

- The maximum force exertion capability of children (K-2) on the rear emergency door handle is less than the permissible force in the high force region (40 pounds).

$$H_0 : F_{\text{exerted by K-2 children}} \geq 40 \text{ pounds}$$

$$H_1 : F_{\text{exerted by K-2 children}} < 40 \text{ pounds}$$

- Mean self extrication time through the rear emergency door is improved when the last row of seats is removed.

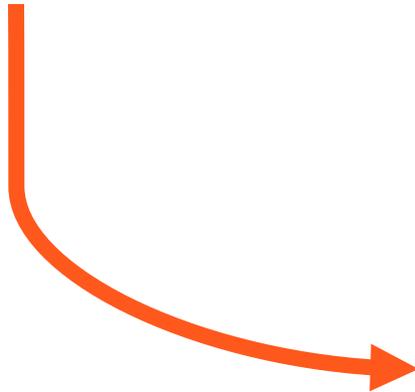
$$H_0 : \mu_{\text{evacuation time without seats}} = \mu_{\text{evacuation time with seats}}$$

$$H_1 : \mu_{\text{evacuation time without seats}} > \mu_{\text{evacuation time with seats}}$$

# Variables

- Independent Variables:
  - Grade Level (Kindergarten, First Grade, and Second Grade)
  - Height (inches)
  - Weight (pounds)
  - Gender
- Dependent Variables:
  - Force exertion on the door handle in simulated upright and rolled over orientations.
  - Time to self-extricate through the emergency exit opening in a rolled over orientation.

# Test Apparatus



# Force Measurement Apparatus



# Subjects

- 126 subjects in K-2 were recruited from Oak Mountain Elementary School (Birmingham, AL).

<b>Grade</b>	<b>Males</b>	<b>Females</b>	<b>Total</b>
Kindergarten	22	17	39
1st Grade	21	25	46
2nd Grade	23	18	41
<b>Total</b>	<b>66</b>	<b>60</b>	<b>126</b>

# Data Collection

- **Station 1:**
  - Gender, Grade, Date of Birth (month/year), Height, Weight
- **Station 2:**
  - Maximum Force exertion on door handle (upright and rolled-over orientations).
  - Three 3-second trials with 30 second rest interval between trials.
- **Station 3:**
  - Unlatch the door (upright and rolled over orientation).
  - Self extricate through the apparatus in the rolled over orientation (with and without the last row of seats).

# Results

- Kindergarten: Two males and two females were unable to unlatch the door in the upright orientation. Two females were unable to self-extricate through the door opening in the original rear seat configuration.
- First Grade: One male and one female were unable to self-extricate through the door opening in the original rear seat configuration.
- Second Grade: One female was unable to self-extricate through the door opening in the original rear seat configuration.

<b>Kindergarten</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Minimum</b>	<b>Maximum</b>
Maximum Pull Force in Upright Orientation (lb)	14.6	6.7	2.3	30.7
Maximum Pull Force in Rolled-Over Orientation (lb)	13.4	6.7	3.0	31.9
Time to Self Extricate with Rear Seat (seconds)	6.4	2.8	2.8	15.3
Time to Self Extricate without Rear Seat (seconds)	3.5	1.6	1.7	8.6
<b>1st Grade</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Minimum</b>	<b>Maximum</b>
Maximum Pull Force in Upright Orientation (lb)	19.6	7.2	8.7	42.7
Maximum Pull Force in Rolled-Over Orientation (lb)	18.6	7.4	9.5	35.5
Time to Self Extricate with Rear Seat (seconds)	5.6	3.7	2.1	20.9
Time to Self Extricate without Rear Seat (seconds)	2.3	0.9	1.0	4.9
<b>2nd Grade</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Minimum</b>	<b>Maximum</b>
Maximum Pull Force in Upright Orientation (lb)	23.6	7.0	12.2	42.8
Maximum Pull Force in Rolled-Over Orientation (lb)	18.8	6.9	9.2	35.8
Time to Self Extricate with Rear Seat (seconds)	4.4	1.9	1.5	8.1
Time to Self Extricate without Rear Seat (seconds)	1.7	0.7	0.8	4.1

# Results: Force Exertions

- **One-sample t-test:**  $H_0: \mu \geq 40$  pounds:

Grade / Exertion Type	N	Upper Bound	T-Value	P-Value
Kindergarten Upright Orientation Force Exertion	38	16.45	-23.36	0.000
Kindergarten Rolled-Over Orientation Force Exertion	35	15.28	-23.60	0.000
1st Grade Upright Orientation Force Exertion	46	21.41	-19.29	0.000
1st Grade Rolled-Over Orientation Force Exertion	44	20.46	-19.30	0.000
2nd Grade Upright Orientation Force Exertion	41	25.43	-15.07	0.000
2nd Grade Rolled-Over Orientation Force Exertion	39	20.72	-19.06	0.000

- **Paired t-test:** Mean force exertion in upright orientation is greater than mean force exertion in rolled over orientation ( $p = 0.002$ )

# Results: Force Exertions

- ANCOVA: **Grade, weight and gender** had a statistically significant effect on force exertion in the **upright orientation**.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	3317.36	663.472	18.85	0.000
Weight	1	962.41	962.413	27.35	0.000
Height	1	17.79	17.786	0.51	0.479
Grade	2	592.96	296.482	8.42	0.000
Gender	1	353.23	353.230	10.04	0.002
Error	119	4187.81	35.192		
Lack-of-Fit	118	4187.48	35.487	106.42	0.077
Pure Error	1	0.33	0.333		
Total	124	7505.17			

- ANCOVA: **Weight and Gender** had a statistically significant effect on force exertion in the **rolled-over orientation**.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	1767.26	353.452	7.13	0.000
Weight	1	605.25	605.248	12.21	0.001
Height	1	0.45	0.454	0.01	0.924
Grade	2	152.70	76.352	1.54	0.219
Gender	1	194.17	194.175	3.92	0.050
Error	112	5553.99	49.589		
Lack-of-Fit	111	5551.84	50.017	23.23	0.164
Pure Error	1	2.15	2.153		
Total	117	7321.25			

# Results: Self-Extrication

- ANCOVA: Height had a statistically significant effect on self-extrication time for trials with and without seat obstruction ( $p < 0.05$ ).
- Paired t-test: Mean self-extrication time through the emergency door opening with seat obstruction is greater than evacuation time without seat obstruction ( $p < 0.05$ ).

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	63.512	21.1705	2.43	0.069
Weight	1	12.990	12.9895	1.49	0.225
Height	1	50.932	50.9318	5.84	0.017
Gender	1	2.177	2.1766	0.25	0.618
Error	105	915.032	8.7146		
Lack-of-Fit	104	914.766	8.7958	33.01	0.138
Pure Error	1	0.266	0.2665		
Total	108	978.544			

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	35.549	11.8498	8.46	0.000
Weight	1	2.472	2.4717	1.76	0.187
Height	1	12.456	12.4561	8.89	0.004
Gender	1	0.181	0.1811	0.13	0.720
Error	108	151.347	1.4014		
Lack-of-Fit	107	151.246	1.4135	13.96	0.211
Pure Error	1	0.101	0.1012		
Total	111	186.896			

# Discussion & Conclusions

- Force exertion data suggests that children in K-2 do not have the strength capabilities to exert the maximum permissible force to unlatch an exit in the high force region.
- Flow rates with the original seat configuration are approximately half of the flow rates without the seat.

Grade / Configuration	Flow Rate (PPM)	Standard Deviation	Maximum	Minimum
Kindergarten With Seat	11	4	22	4
Kindergarten Without Seat	20	7	36	7
1st Grade With Seat	14	6	28	3
1st Grade Without Seat	30	11	60	12
2nd Grade With Seat	16	7	39	7
2nd Grade Without Seat	41	14	80	14

# Discussion & Conclusions

- The last row of seats impedes the evacuation process.



# Study 2: Roof Hatch Evacuations

- Measure the maximum push force and torque that can be exerted on a roof hatch knob.
- Determine if K-2 children are capable of opening a school bus emergency escape roof hatch.
- Determine if K-2 children have the capability to self-extricate through and emergency escape roof hatch.

# Study 2 Hypotheses

- The maximum push force exertion on the roof hatch knob for children in K-2 is less than the force required to open a roof hatch (20 pounds).

$$H_0 : \mu_{\text{force exerted by children K-2}} \geq 89 \text{ Newtons}$$

$$H_1 : \mu_{\text{force exerted by children K-2}} < 89 \text{ Newtons}$$

- Percentage of successful evacuations increases with the grade level of the children.

$$H_0 : N_{\text{Kindergarten evacuations}} = N_{\text{First grade evacuations}} = N_{\text{Second grade evacuations}}$$

$$H_1 : N_{\text{Kindergarten evacuations}} < N_{\text{First grade evacuations}} < N_{\text{Second grade evacuations}}$$

# Variables

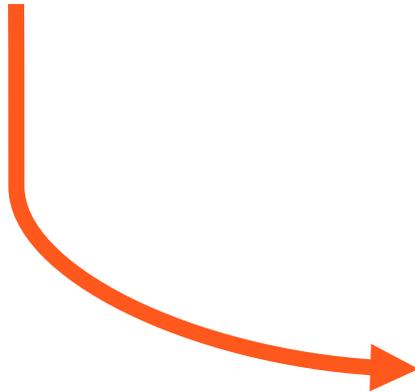
- Independent Variables:
  - Grade Level (K-2)
  - Height
  - Weight
  - Gender
  - Hand Length and Hand Width
- Dependent Variables:
  - Push Force and Torque Exertions
  - Ability to operate the release mechanism
  - Ability to self-extricate through the roof hatch

# Subjects

- 91 (51 males, 40 females) subjects in K-2 were recruited from Jim Pearson Elementary (Alexander City, AL)

Grade	Males	Females	Total
Kindergarten	18	12	30
1st Grade	19	15	34
2nd Grade	14	13	27
Total	51	40	91

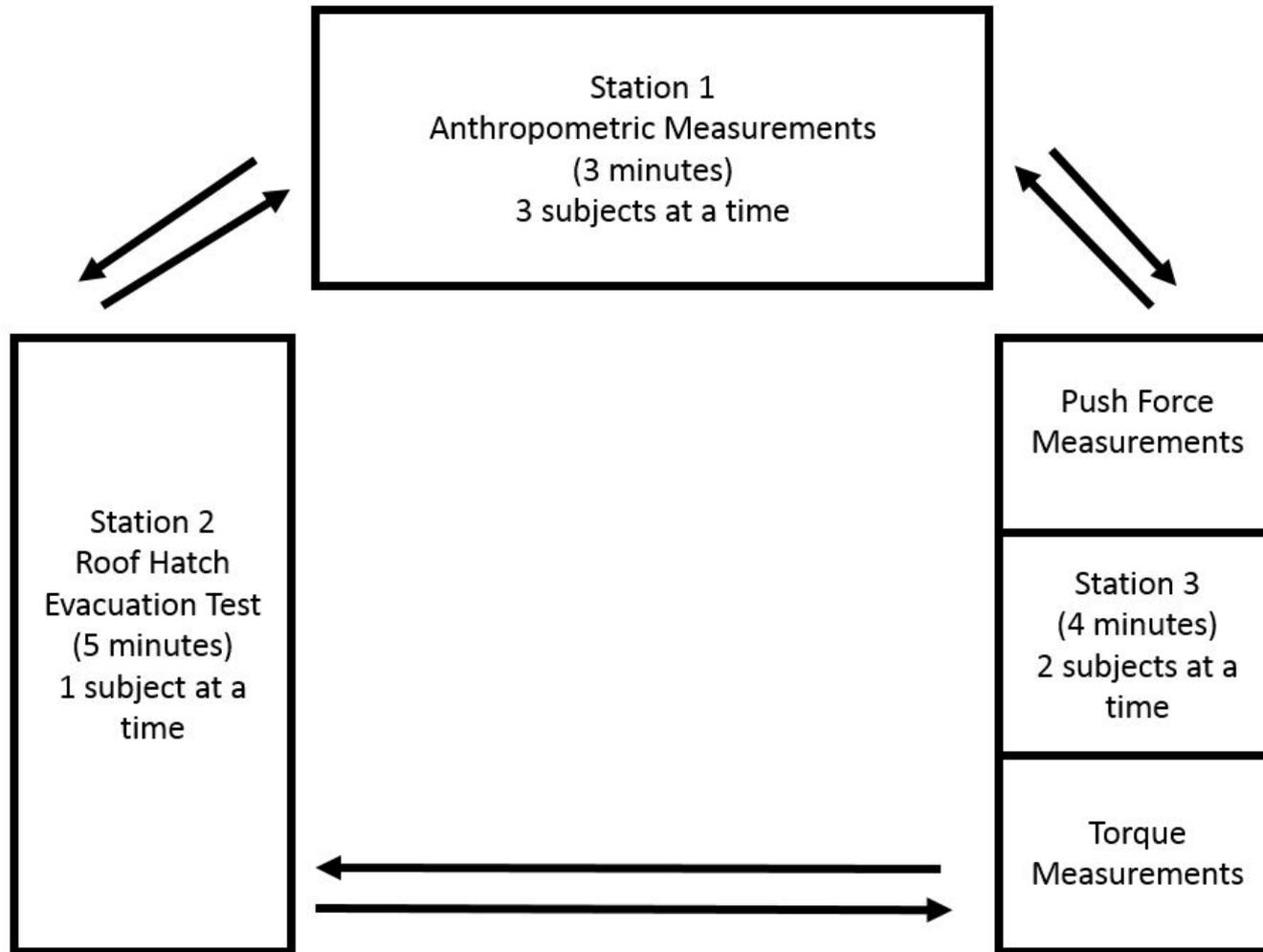
# Test Apparatus



# Test Equipment



# Data Collection



# Results

- Only 21% (6/30) of the kindergarten participants were able to open the roof hatch and 87% (26/30) were able and willing to self-extricate (2 males, 2 females were unable to self-extricate).
- 71% (24/34) of the 1<sup>st</sup> grade participants were able to open the roof hatch and 91% (31/34) were able and willing to self-extricate (1 female did not want to participate in opening and extricating through the roof hatch).
- 89% (24/27) of the 2<sup>nd</sup> grade participants were able to open the roof hatch and 96% (26/27) were able and willing to self-extricate (1 male was unable to self-extricate).

<b>Kindergarten (N=30)</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Maximum</b>	<b>Minimum</b>
Maximum Torque Trial (Nm)	1.855	0.485	2.595	0.935
Maximum Push Force Trial (N)	79.1	26.29	142	32
Time from touching roof hatch to hatch unlatched (seconds)	9.1	4.8	17.9	3.7
Time from hatch unlatched to entire body on other side of hatch (seconds)	6.9	3.6	15.9	2.5
<b>1st Grade (N=34)</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Maximum</b>	<b>Minimum</b>
Maximum Torque Trial (Nm)	2.427	0.604	4.110	1.220
Maximum Push Force Trial (N)	101.3	26.58	168	30
Time from touching roof hatch to hatch unlatched (seconds)	7.20	3.42	14.89	2.22
Time from hatch unlatched to entire body on other side of hatch (seconds)	5.21	2.94	17.88	1.06
<b>2nd Grade (N=27)</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Maximum</b>	<b>Minimum</b>
Maximum Torque Trial (Nm)	2.911	0.954	4.750	0.930
Maximum Push Force Trial (N)	125.2	37.20	240	66
Time from touching roof hatch to hatch unlatched (seconds)	5.22	2.89	12.18	1.37
Time from hatch unlatched to entire body on other side of hatch (seconds)	5.69	5.06	28.75	2.31

# Results: Push Force

- Maximum Push Force Best Subsets Regression

Vars	R-Sq	Adj. R-Sq	Pred. R-Sq	Cp	S	Grade	Gender	Height	Weight	Hand Length	Hand Width
1	48.2	47.6	44.4	17.7	25.224			x			
1	45.8	45.1	41.9	22.5	25.806				x		
2	55.9	54.8	50.6	4.5	23.416				x		x
2	53.5	52.4	47.3	9.1	24.026			x	x		
3	57.0	55.4	50.8	4.3	23.255		x		x		x
3	57.0	55.4	50.8	4.3	23.256				x	x	x
4	57.9	55.8	51.0	4.5	23.150		x		x	x	x
4	57.6	55.6	50.6	5.0	23.214	x			x	x	x
5	58.5	56.0	50.7	5.3	23.110	x	x		x	x	x
5	58.2	55.7	49.6	5.9	23.197		x	x	x	x	x
6	58.6	55.6	49.2	7.0	23.215	x	x	x	x	x	x

- Weight** and **hand length** had a statistically significant effect on push force ( $p < 0.05$ ) (adj.  $R^2 = 58.61\%$ )

# Results: Roof Hatch Evacuations

- Factors having a statistically significant (or nearly so) effect on opening the roof hatch:
  - Hand Length ( $p < 0.05$ )
  - Weight ( $p = 0.055$ )
- No variables were found to have a statistically significant effect on self-extrication.

# Discussion & Conclusions

- Overall in K-2, 58% of the subjects were able to exert more than 89 Newtons of force. However in kindergarten, only 40% of subjects were able to exert more than 89 Newtons of force.



# Discussion & Conclusions

- In summary, 40% (36/91) of the subjects were unable to open the roof hatch. However, 28% (10/36) were able to exert a push force exceeding 89 Newtons.



# Discussion & Conclusions

- Reasons subjects were unable to self-extricate through roof hatch:
  - Apparent insufficient upper body strength.
  - Low friction between the smooth ceiling surface and subjects' feet.

# Study 3: Evacuation Times

- Measure the evacuation time of subjects in kindergarten through the third grade (**K-3**) (by grade) through the **front door** (stand alone), **rear emergency door** (stand alone), and both the **front and rear exits simultaneously**.
- Compare evacuation rates with the **bus driver's assistance/guidance** to unguided evacuation rates.
- Determine the **effectiveness of the emergency exit doors** by measuring **flow rate** (people per minute) of the front (stand alone) and rear (stand alone) emergency exit doors, as well as both simultaneously.

# Importance of Egress Time

- Egress time is critical in accidents. Bus fire tests indicate that available time for successful evacuations is between 200-300 seconds (~3-5 minutes) [Matolcsy, 2010].
- Factors that can impact egress times [Sliepcevich, C.M., et al., 1972]:
  - Smoke
  - Fire
  - Visibility
  - Injuries
  - Age/Experience
  - Strength and Agility
  - Opening Size

# Hypotheses

- There is a significant difference among the mean flow rates of the different grade levels.

$$H_0 : \mu_k = \mu_1 = \mu_2 = \mu_3$$

$$H_1 : \mu_k \neq \mu_1 \neq \mu_2 \neq \mu_3$$

- There is a significant difference in the flow rates of evacuation with bus driver assistance compared to evacuation without bus driver assistance.

$$H_0 : \mu_{with\ assistance} = \mu_{without\ assistance}$$

$$H_1 : \mu_{with\ assistance} < \mu_{without\ assistance}$$

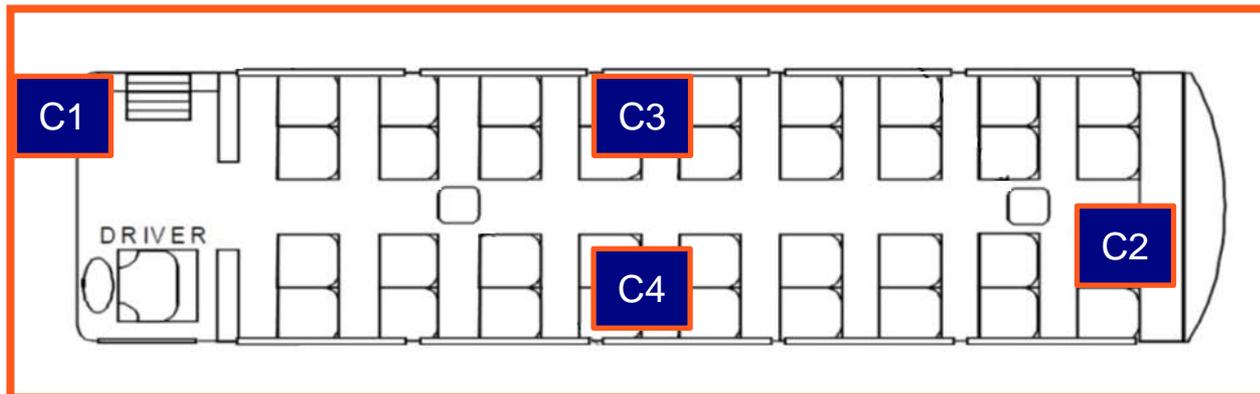
# Subjects and Data Collection

- 475 students (251 males, and 224 females) in K-3 were recruited from Oak Mountain Elementary School (Birmingham, AL).

Grade Level / No. of Participants	Driver Assistance	Evacuation 1	Evacuation 2	Evacuation 3
Kindergarten, N = 60 (30 M, 30 F)	Yes	Front Door	Front & Rear Doors	N/A
Kindergarten, N = 56 (28 M, 28 F)	No	Rear Door	Front & Rear Doors	Front Door
First Grade, N = 57 (30 M, 27 F)	Yes	Rear Door	Front & Rear Doors	Front Door
First Grade, N = 52 (25 M, 27 F)	No	Front & Rear Doors	Rear Door	Front Door
Second Grade N = 63 (30 M, 33 F)	Yes	Front & Rear Doors	Front Door	Rear Door
Second Grade, N = 63 (34 M, 29 F)	No	Rear Door	Front & Rear Doors	Front Door
Third Grade N = 61 (36 M, 25 F)	Yes	Front Door	Rear Door	Front & Rear Doors
Third Grade, N = 63 (38 M, 25 F)	No	Rear Door	Front & Rear Doors	Front Door

# Data Collection

- 2009 Thomas C2 SAF-T-LINER
  - 12 rows of seats
  - Max capacity: 72 passengers



# Results: Flow Rates

Evacuation Times with Driver's Assistance and Guidance (Seconds)

Grade	Front Door	Rear Door	Both Doors
Kindergarten (N = 60)	225	N/A	135
1st Grade (N = 57)	120	169	111
2nd Grade (N = 63)	111	179	98
3rd Grade (N = 61)	103	180	76
Mean (SD)	139.8 (57.3)	176 (6.1)	105 (24.7)

Evacuation Times without Driver's Assistance and Guidance (Seconds)

Grade	Front Door	Rear Door	Both Doors
Kindergarten (N = 56)	133	238	170
1st Grade (N = 52)	139	180	114
2nd Grade (N = 63)	129	204	97
3rd Grade (N = 63)	114	179	68
Mean (SD)	128.8 (10.7)	200.3 (27.7)	112.3 (42.9)

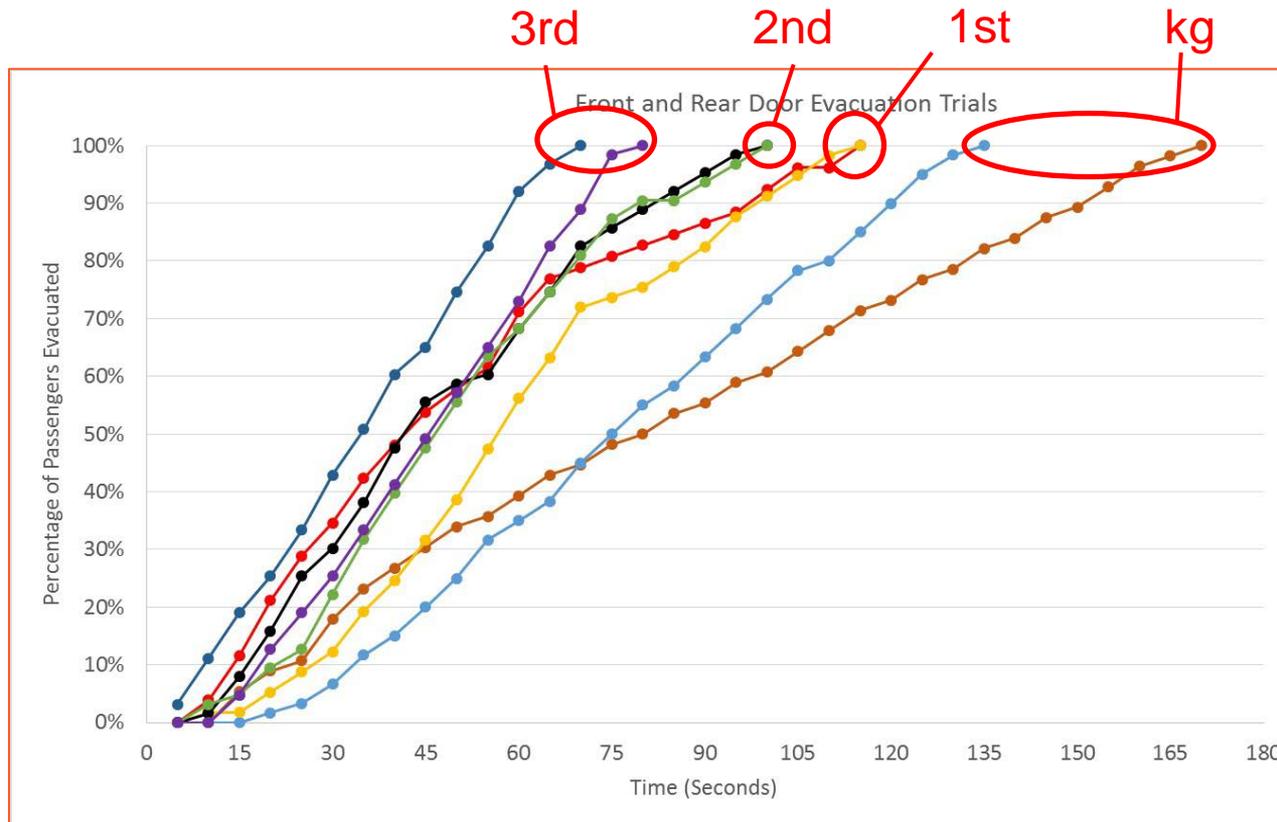
Flow Rate with Driver's Assistance and Guidance (People/Minute)

Grade	Front Door	Rear Door	Both Doors
Kindergarten (N = 60)	16	N/A	27
1st Grade (N = 57)	29	20	31
2nd Grade (N = 63)	34	21	39
3rd Grade (N = 61)	36	20	48
Mean (SD)	29 (8.9)	21 (0.5)	36 (9.5)

Flow Rate without Driver's Assistance and Guidance (People/Minute)

Grade	Front Door	Rear Door	Both Doors
Kindergarten (N = 56)	25	14	20
1st Grade (N = 52)	22	17	27
2nd Grade (N = 63)	29	19	39
3rd Grade (N = 63)	33	21	56
Mean (SD)	28 (4.7)	18 (2.9)	35 (15.6)

# Results: Flow Rates



# Factors Affecting Flow Rates

- Factors that had a statistically significant effect on flow rates:
  - Exit Type
  - Grade Level

Source	DF	SS	MS	F-Value	P-Value
Driver	1	4.72	4.732	0.23	0.6551
Grade	3	746.61	248.871	11.87	0.0104
Door	2	1018.12	509.062	24.27	0.0027
Driver*Grade	3	40.35	13.451	0.64	0.6206
Driver*Door	2	0.81	0.406	0.02	0.9809
Grade*Door	6	289.92	48.321	2.3	0.1889
Error	5	104.85	20.971		
Total	22				

# Effects of Grade and Evacuation Routes

- Tukey Pairwise Comparison: Flow rates were statistically different between ( $p < 0.05$ ):
  - Kindergarten and third grade
  - First grade and third grade
  - Kindergarten and second grade
- Mean flow rates of the front door evacuations, rear door evacuations, and both door (simultaneously) evacuations were found to be significantly different ( $p < 0.05$ )

Grade	Mean	Homogeneous Groups <sup>†</sup>
Kindergarten	35.7	A
First	30.2	AB
Second	24.3	BC
Third	19.1	C

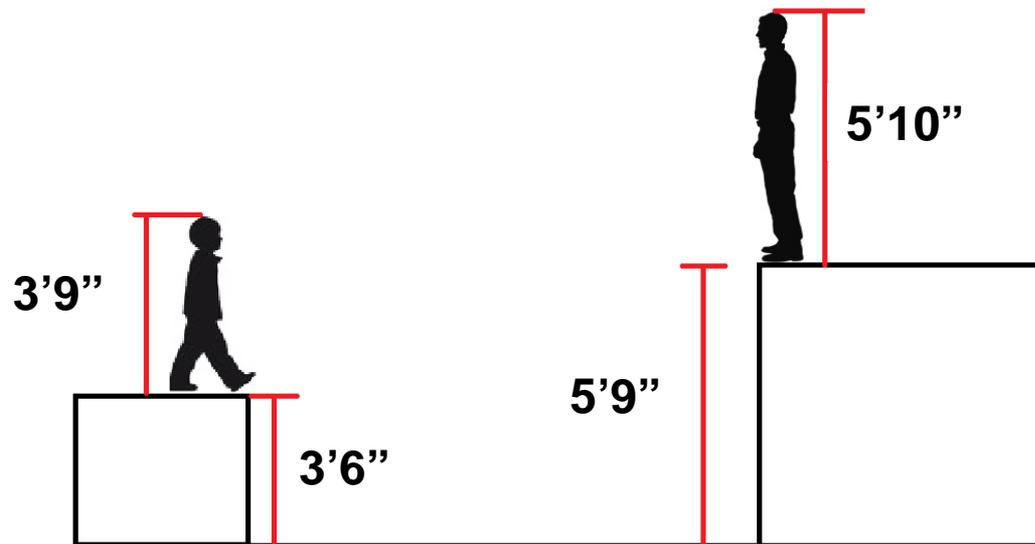
<sup>†</sup> Means that do not share a letter are significantly different.

Evacuation Scenario	Mean	Homogeneous Groups <sup>†</sup>
Front and Rear Door Evacuation	35.9	A
Front Door Evacuation	28.0	B
Rear Door Evacuation	18.1	C

<sup>†</sup> Means that do not share a letter are significantly different.

# Discussion & Conclusions

- Elevation of emergency door off the ground is a concern during rear door evacuations, children were asked to “sit and scoot” during the evacuation process.



# Discussion & Conclusions

- Distribution of evacuees between the front and rear doors in the both doors (simultaneous) evacuations.
  - Distribution between exits more equal with older children and evacuation trials with driver's assistance.

Driver Assistance	Grade Level	Front Door	Rear Door
Yes	Kindergarten	50%	50%
No	Kindergarten	14%	86%
Yes	First Grade	44%	56%
No	First Grade	46%	54%
Yes	Second Grade	49%	51%
No	Second Grade	51%	49%
Yes	Third Grade	59%	41%
No	Third Grade	62%	38%

# Acknowledgements

- Mr. Kevin Snowden (Former Alabama State Transportation Director)
- Mrs. Debbie Horton (Principal, Oak Mountain Elementary School)
- Mr. Jamie Forbus (Principal, Jim Pearson Elementary)
- Blue Bird Bus Corporation for the bus mock-up and assistance.
- Chief Lankford and Auburn Fire Department for their assistance with the mock-up.

# Questions?

- Contact Information:
  - Joe Abulhassan
  - Cell: 503-880-5045
  - E-mail: [yabulhassan@murraystate.edu](mailto:yabulhassan@murraystate.edu)