DOT/FAA/AM-04/12

Office of Aerospace Medicine
Washington, DC 20591

Simulated Evacuations Into Water

Garnet A. McLean
David A. Palmerton
Cynthia L. Corbett
Kenneth G. Larcher
Jerry R. McDown

Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

August 2004

Final Report

U.S. Department
of Transportation

**Federal Aviation
Administration**

NOTICE

Technical Report Documentation Page

Report No. DOT/FAA/AM-04/12	2. Government Accession No.	3. Recipient's Catalog No.
4. Title And Subtitle Simulated Evacuations Into Water		5. Report Date August 2004
7. Author(s) McLean GA, Palmerton DA, Corbett CL, Larcher KG, McDown JR		8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125		
12. Sponsoring Agency Name and Address Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave. Washington, DC 20591		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
15. Supplemental Notes This work was performed under task AM-B-01-PRS-93.		13. Type of Report and Period Covered
		14. Sponsoring Agency Code

16. Abstract

Introduction. Transport airplanes are required to be assessed for ditching capability in the FAA type-certification process. This includes the airplane's emergency evacuation potential, i.e., the ability of passengers to escape the airplane after it lands on water. Actual emergency data to support ditching certification are not available; there have been questions as to whether evacuation flow rates onto land are appropriate for use in ditching-related flotation time computations. Simulated evacuations from platforms into the CAMI survival tank were conducted to obtain passenger flow rate data that can be used to support the certification process. **Methods**. A 12' x 12' platform was placed next to the tank. Platform (exit sill) heights of 9", 2', 4', and 6' were employed; flotation seat cushions and inflatable life vests were used as individual flotation aids. Four subject groups performed 3 simulated evacuations at each platform height through a Type-I exit-sized opening; 4 other groups similarly used a Type-A exit-sized opening. **Results**. A significant effect ($p<.001$) of platform height above the water was found, as increasing heights resulted in monotonic decreases in flow rate. A significant effect ($p<.01$) of flotation device type was also found, with flotation seat cushions producing the lowest flow rates, followed next by life vests that were uninflated until entry into the water, and then life vests that had been inflated before leaving the platform. Finally, the Type-A exit-sized platform configuration was significantly faster than was the Type-I configuration ($p<.05$). **Conclusion**. These effects suggest that in the best conditions, passenger flow rates into water are much like those onto land. However, the platform height effects suggest that airplane attitude in the water may be important, as is exit size. The use of flotation seat cushions as flotation aids should be a last resort.

17. Key Words Aircraft Evacuation, Passageway Configuration, Hatch Operation, Competitive Egress, Individual Subject Characteristics, Passenger Management		18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 12	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

The authors gratefully acknowledge the untiring efforts of those who gave so generously of their time and energy toward the success of this project. The dedication each of them displayed is a tribute to the professionalism embodied in the personnel of the Civil Aerospace Medical Institute and their willingness to assist. Among all those who contributed, special thanks go to our research support staff:

April Baker
Rick Butler
Donna Cosper
David DeSelms
Rick DeWeese
Dave Dyer
Ronnie Minnick
Bryan Provine
Lori Samuel
Robert Shaffstall
Steve Veronneau
James Whinnery
Greg Winters

Simulated Evacuations Into Water

INTRODUCTION

Certification procedures for transport airplane evacuation capability are well defined in Federal Aviation Regulations; however, evacuation procedures for ditching scenarios, in which passengers must evacuate into life rafts or into the water, are not specified in those requirements. Part 25.801(d) of 14 CFR (1) states, "it must be shown that, under reasonably probable water conditions, the flotation time and trim of the airplane will allow the occupants to leave the airplane and enter the liferafts required by § 25.1415 (1)."

This requirement has generally been demonstrated via the use of a flotation-time analysis for each new airplane type. The proposed design and operation of new, very large transport airplanes, e.g., double-deck airplanes that will conduct many extended over-water operations, raise questions regarding some of the assumptions in the flotation-time analyses. Specifically, the distance of very large airplane lower deck exit sills above the water line has been predicted to range in a successful ditching from just a few inches to about 6 ft. This may create significant deviations from the passenger flow rates into the water assumed historically for transport airplanes, especially those caused in part by the speed with which passengers can vacate the area immediately adjacent to the aircraft exit once they have entered the water. Such deviations may also exist for new narrow-body airplane types with long fuselages, for which unfavorable flotation attitudes could also produce exit sill heights from water level to several feet, especially for exits at the ends of the fuselage. Differences in personal flotation devices and their modes of operation can add to such variances, as can the exit type through which passengers must egress.

To provide information relative to these certification questions, the Civil Aerospace Medical Institute (CAMI) Protection and Survival Research Laboratory conducted a study using its water survival research tank to evaluate simulated egress into water. Subjects jumped from a platform, configured with a simulated Type A (42" wide) dual-lane floor-level exit or a simulated Type I (24" wide) single-lane floor-level exit, erected at heights of 0.75, 2, 4, and 6 feet above the surface of the water. Three different personal flotation device conditions were also investigated; subjects jumped into the water: 1) while holding typical transport airplane flotation seat cushions, 2) while wearing an inflatable life vest (inflated) approved to Technical Standard Order (TSO-C13), or 3) while wearing the TSO-approved life vest (uninflated) until after entering the water and then inflating it.

The goal of the research project was to provide best-case estimates of the egress times (flow rates) into water that could be expected through each of the simulated exit types, at each of the simulated exit sill heights, for each of the different personal flotation device conditions.

METHODS

Experimental design. Four groups of 20 to 31 (mean = 25) participants completed 12 experimental evacuation trials in a 3 (flotation device) by 4 (platform height) repeated-measures design (Table 1), using either

Table 1. Experimental Design

Flotation device order	S VU VI	VI S VU	S VI VU	VU S VI
Group 1 platform order	.75'	2'	4'	6'
Group 2 platform order	6'	4'	2'	.75'
Group 3 platform order	4'	6'	.75'	2'
Group 4 platform order	2'	.75'	6'	4'

S = Seat cushion / VI = Vest inflated / VU = Vest uninflated the Type A or Type I exit. Flotation-device and platform-height conditions were counterbalanced within each group to minimize bias.

Subjects. Two hundred medically-fit participants, ranging in age from 18 to 50 years of age, weighing less than 300 lbs. each, divided almost evenly with respect to gender (m = 95 / f = 105), and with the ability to swim 2 lengths of the CAMI survival tank, were employed in the study. They wore long pants, a T-shirt style top, and shoes; they also wore a TSO C-13 approved inflatable life vest or clutched a typical transport airplane flotation seat cushion.

Safety Personnel. Two Red Cross/CPR-certified lifeguards were stationed at the edge of the water alongside the survival tank near the platform during all trials and a SCUBA diver was positioned in the water at the side of the platform for water safety concerns. Four additional research personnel were stationed around the pool to provide assistance in the unlikely event that a subject needed to be helped out of the water.

Apparatus. A 144 ft^2 adjustable-height platform (Figure 1), configured to produce either a simulated Type A or Type I exit, was constructed alongside the CAMI survival tank. The platform was essentially 12' x 12' square, except that a 4' x 4' section at the left rear of the platform was removed and replaced with stairs, with the removed section being attached to the center of the platform at the edge of the survival tank to form a protruding "passageway" that participants used to approach the simulated exit. A 3-ft high side rail was erected around the platform for participant safety, except that the rail did not enclose the front edge of the section protruding over the water.

The side rails along this section of the platform were fitted with foam blocks to exactly establish the width of the passageway/exit at either 24" or 42", depending on the experimental condition (Figure 2). The sliding doors of the survival tank facility were nestled against the side edges of the protruding platform section to serve as a simulated fuselage and to preclude participants from seeing the activity in the water adjacent to the platform until it was their turn to jump. The platform was erected at 4 different heights (0.75, 2, 4, and 6 ft) above the water for each participant group; this height was readjusted between trials after subjects had completed their egress trials for each height. The minimum (0.75 ft) platform height above the water was as near to the surface of the water as could be physically achieved by the apparatus.

Two flotation devices were used to create 3 flotation-device conditions, as participants: 1) wore a pre-inflated life vest when jumping through the exit and entering the water, 2) wore a non-inflated life vest when jumping through the exit that they inflated upon entering the water, and 3) clutched the flotation seat cushion as they jumped through the exit and entered the water. Video cameras with time-code generators were strategically located to record/time participants jumping from the platform into

Figure 1. Platform Configuration

Figure 2. Passageway/Exit Restriction Produced by Foam Blocks

the water; underwater activity was also recorded by video camera from below (Figure 3).

Procedure. Participants completed the necessary paperwork/medical screening and were tested for their ability to swim 2 lengths of the CAMI survival tank before being allowed to enter the experimental phase of the study. They were then briefed about the scenario to be followed for the simulated evacuations, i.e., they were flying in an airplane that had an emergency landing on water and was rapidly sinking. They had to "get out" by jumping as fast as possible through the exit into the water and moving away from the airplane as quickly as possible toward a life raft (placed across the survival tank) that had been deployed in the water. Importantly, however, they were also told that they must not jump onto any of their fellow passengers who were already in the water. They were then shown how to operate an inflatable life vest (Figure 4), as well as the proper way to hold a flotation seat cushion (Figure 5). Once the briefings were completed and any questions answered, they were provided with either a life vest or a flotation seat cushion and directed to the platform, where they climbed the stairs and formed either a dual-lane queue to the simulated Type-A exit or a single-lane queue to the simulated Type I exit. (Note that only 1 exit type was used by any group; in contrast, each group performed in all 3 flotation device conditions and at all 4 platform heights.)

Each trial began with a verbal start signal (GO!), whereupon the participants began to jump into the water, inflate their life vests (if necessary), and kick/swim/move quickly away from the area beneath the exit toward the life raft across the survival tank to allow succeeding participants to egress as quickly as possible. After each experimental trial was completed, participants climbed from the tank, received the flotation device appropriate for the next trial, and returned to the platform to regroup for the next trial. After the 3 trials at any 1 platform height were completed, participants waited at the shallow end of the tank for the platform to be reconfigured to the next height.

RESULTS

Participant group sizes ranged from 21 to 31 (mean = 25), making group times inappropriate for comparison. Consequently, average individual egress times were calculated. In general, individual egress times into the water for the simulated Type A (dual-lane) passageway/ exit were somewhat shorter than those achieved with the simulated Type I (single-lane) passageway/ exit, owing to the ability of the larger passageway/exit to accommodate simultaneous or staggered egress. The small (0.16 sec) difference was marginally significant ($p<.05$). No interactions of exit type were found with either platform height or flotation device.

Figure 3. Underwater Observation

Figure 4. Proper Method to Inflate Life Vest

Figure 5. Proper Method to Hold Seat Cushion

The effects of platform height ($p<.0001$) on individual egress were more robust, with egress times increasing 0.71 seconds per person, on average, as the height of the platform was increased from 9 in to 6 ft above the water. Post hoc analyses showed that both the 4-ft and 6-ft platform heights produced statistically slower individual egress than that achieved at 2 ft and below, and the 6-ft high platform yielded significantly slower egress than that at 4 ft (Duncan's; $p<.05$). Figures 6 and 7 show the effects of platform height for each exit type. A significant effect of flotation device type on individual egress time was also found ($p<.01$), with the use of flotation seat cushions resulting in individual egress that was 0.25 sec per person slower, on average, than egress with inflatable life vests. No interactions of flotation device type and platform height were found, although a 3-way interactive trend ($p<.06$) of exit type, platform height, and flotation device type was displayed, resulting from particularly slowed egress for participants using the inflated life vest through the Type A, but not the Type I, exit with increasing platform height. Figures 8 and 9 show the effects of flotation device type for each exit type.

DISCUSSION

The effects of platform height and type of flotation device on individual egress time into the water generally conformed to expectation, although the differences in individual egress time related to single-lane versus dual-lane participant flow on the platform and into the water were somewhat smaller than anticipated. Irrespective of exit type, increasing platform height resulted in longer times for participants to jump into the water, much as would be seen at any municipal swimming pool as the height of the diving board increases. Such effects can be related to the fear generally associated with jumping from high places, although the instruction that participants were given about being sure not to jump onto another person already in the water also appeared to play a part.

As the platform height increased, so did the time that participants were underwater or recovering from the jump, making an additional delay necessary for those on the platform to be sure that the prior jumpers were out of the way. This effect occurred for both the Type A and Type I passageway/exit configurations. However, with participants being able to form only a single lane queue to approach the Type I exit and having a wide landing area in the water beneath the platform, this height-related need to wait for prior jumpers to clear the area was minimized relative to the Type A exit configuration.

The Type A exit with the dual-lane queue allowed relatively faster individual egress into the water, resulting in a greater number of jumpers in the landing area at any one time, although this produced a greater need to scan the water to make sure the landing area was clear before jumping. While the difference in hesitation time related to the combination of exit type and platform height was statistically insignificant, it appeared to form much of the basis for the trend toward a 3-way interaction of exit type, platform height, and flotation device type. This trend was additionally dependent on the differential delays in getting away from the landing area produced by the flotation seat cushion and the uninflated life vest, relative to the pre-inflated life vest.

The effects of flotation device type on individual egress times into water appeared to result from both the difficulty participants had moving away from the landing area and the time they spent under water after jumping. The lack of inflation upon entering the water with the uninflated life vest allowed participants to plunge much further into the water, increasing their underwater time in the landing area and, especially when coupled with dual-lane participant flow, resulted in added delays to participants on the platform who had to make sure the water was clear before jumping. The delay occurred even though they could use their arms for swimming, which otherwise should have made for a quick getaway from the landing area.

Like the pre-inflated life vest, immediate flotation upon entering the water was provided by the flotation seat cushion, although the seat cushion, in particular, made moving through the water difficult. This occurred because the cushion formed somewhat of a barrier that had to be pushed through the water to move away from the landing area, and the participant's arms had to be locked around the cushion, eliminating any ability to use them for swimming. This resulted in a *kicking-only* mode of locomotion.

In contrast, the pre-inflated life vest provided the positive benefits of having ready flotation upon entering the water and it allowed participants full use of their arms to swim easily and move away from the landing area with greater speed. This combination of attributes gave the pre-inflated life vest a relative advantage, especially when participants were using the Type-A dual-lane exit configuration, and made it the preferred type of flotation device.

Application of these results to operational and certification decisions would appear rather straightforward, albeit with a caveat or two. First, the operational issue of life vest pre-inflation has long been a question within the industry. The results presented here suggest that, in terms of escape and moving away from a ditched airplane, pre-inflation is a good idea. In mitigation of these findings are accident reports and personal accounts of crash survivors, which indicate that passengers have been and

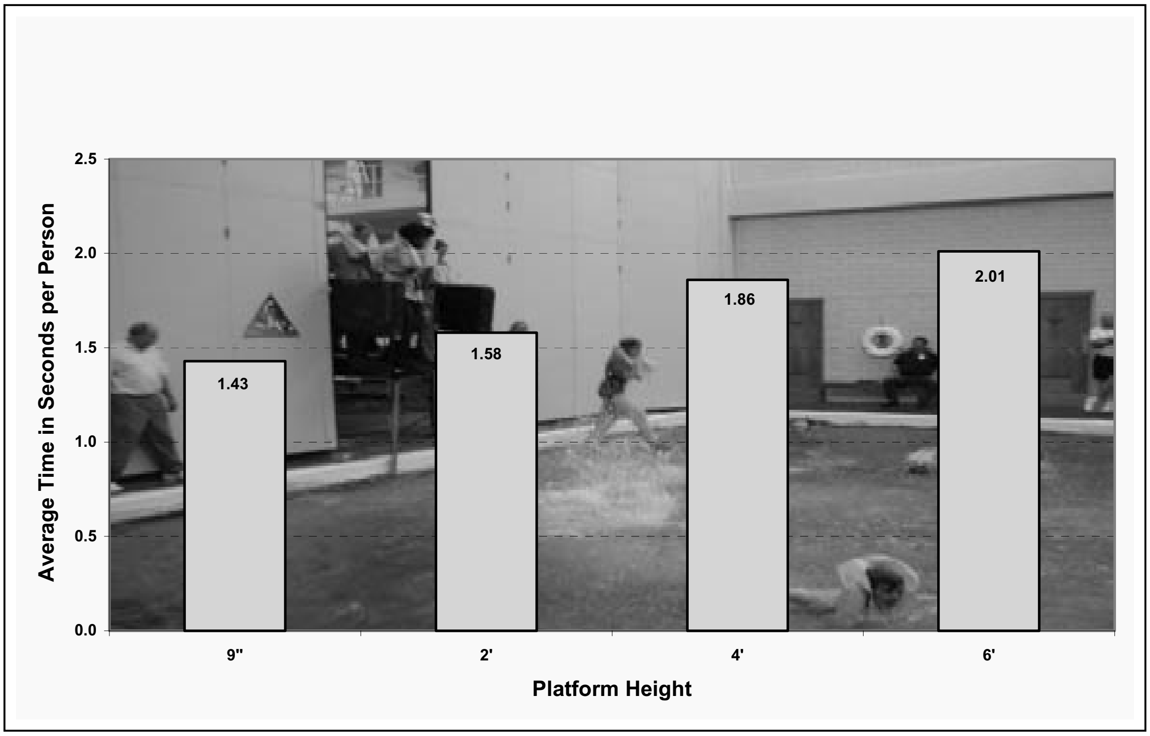

Figure 6. Platform Height Effects With the Type A Exit

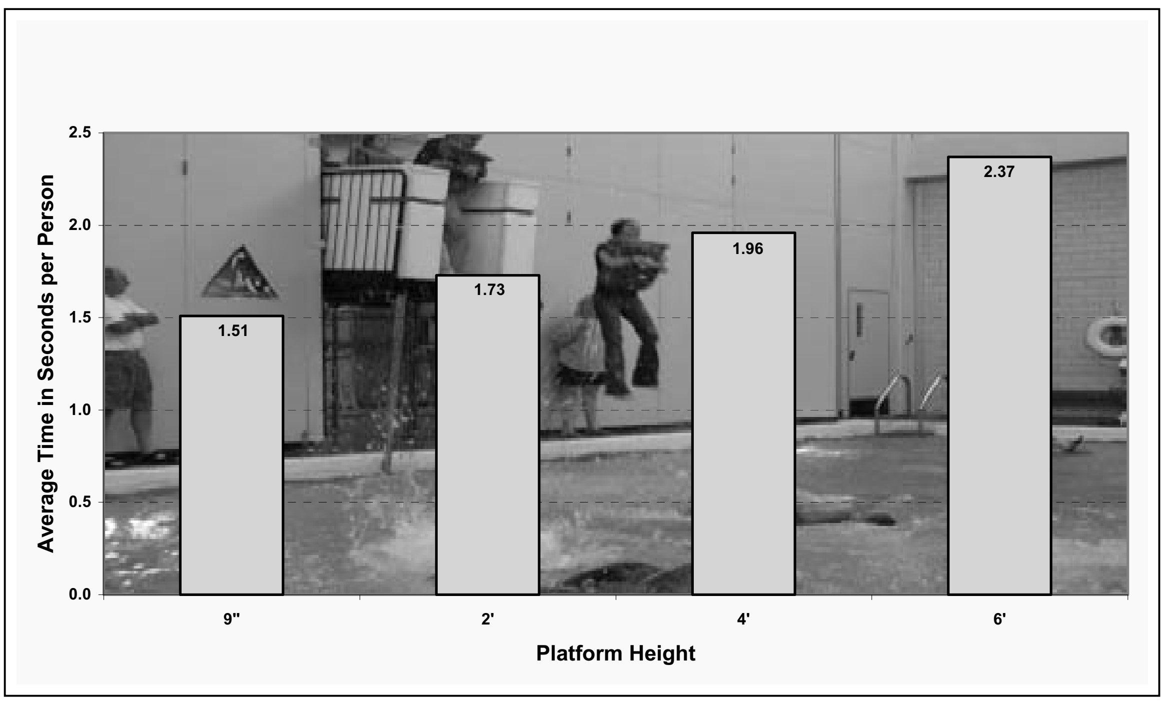

Figure 7. Platform Height Effects With the Type I Exit

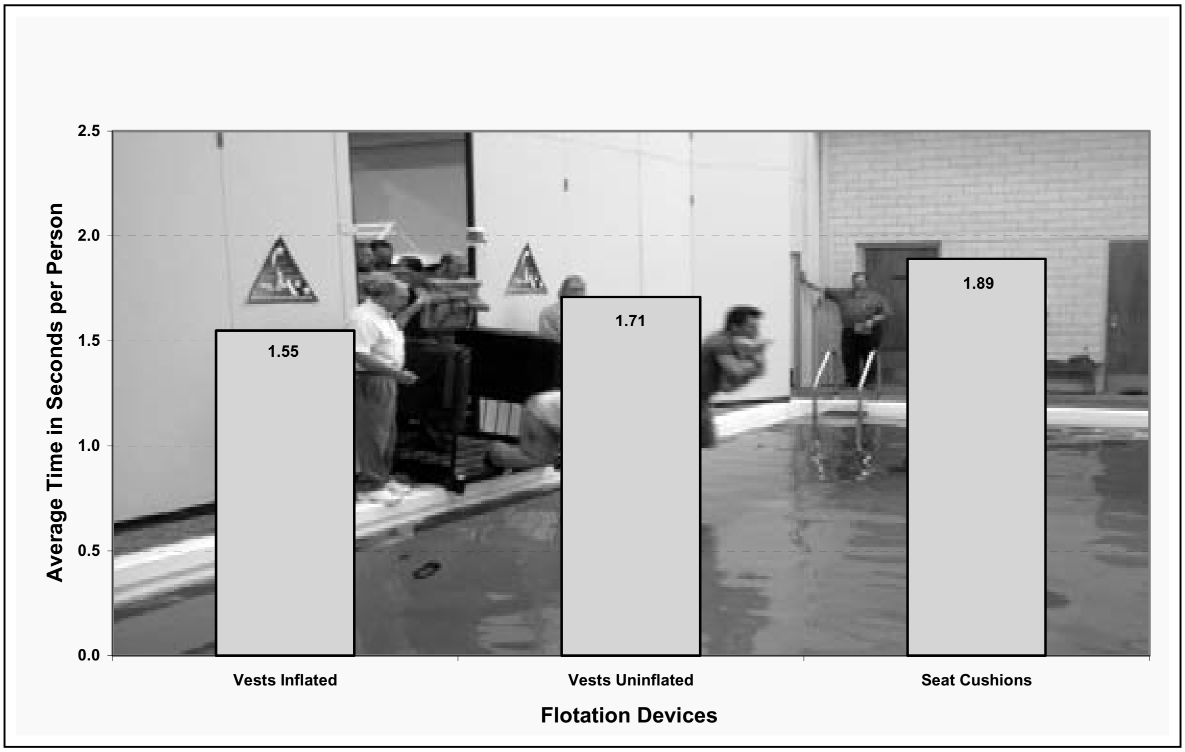

Figure 8. Flotation Device Effects With the Type A Exit

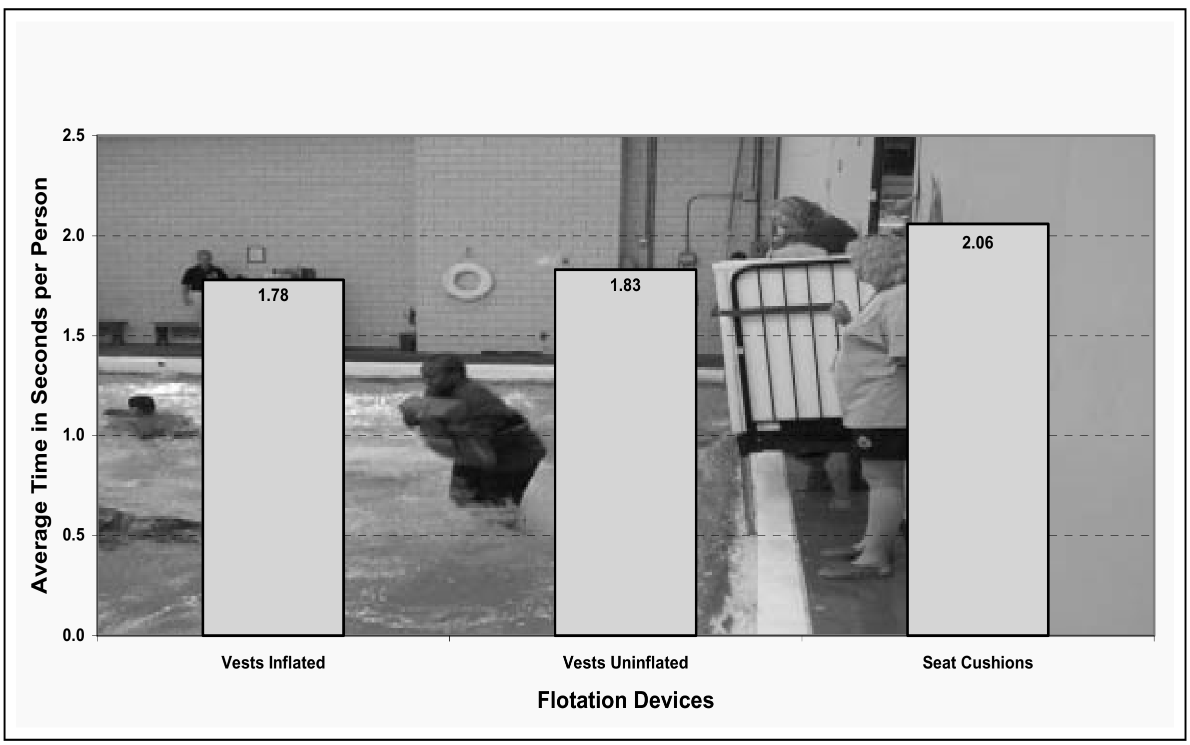

Figure 9. Flotation Device Effects With the Type I Exit

may become trapped inside the airplane should they inflate their vests and the exits then sink below water line. Given both arguments, it would appear that a well-chosen course of action would be to maintain the vests in an uninflated condition until the passenger begins to jump from the airplane exit, pulling the inflation handles in mid-air to create life vest buoyancy before hitting the water.

In addition, in terms of flotation-time analyses and certification decisions, it must be noted that the environmental conditions under which these experimental trials were run were exemplary. Participants were not forced to encounter rough seas, adverse airplane attitudes, disrupted cabin interiors, floating debris, darkness, or extreme temperatures (reasonably probable water conditions of § 25.801(d)), all of which would likely reduce evacuation flow rates significantly. Likewise, participants did not experience the disruptive physical, psychological, and emotional effects of having an emergency landing on water. These, too, would impair decision-making and reduce evacuation flow rates. Thus, the results presented here may be thought of as the upper bounds of what could be expected with regard to emergency evacuation flow rates into water environments, and significant reductions in estimated flow rate below these optimum values should be made unless and until further work has more properly defined the effects of such known emergency contingencies.

REFERENCES

Title 14, US Code of Federal Regulations, Part 25, Sections 801(d) and 1415. Washington, DC: US Government Printing Office, 2003.