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Aircraft Evacuations onto Escape Slides and Platforms II: Effects of Exit Size

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16. Abstract

Experiments were conducted to examine the effects of exit height on subject flow rates during simulated emergency evacuations from an aircraft fuselage. Egress was through (modified) Type-I exits, using inflatable escape slides and doorsill-height platforms configured with ramps for descent to the ground. A single-aisle aircraft simulator was equipped with 30-inch wide rectangular floor-level exits variously configured to achieve overall exit heights of 48, 60, and 72 inches. Human research subjects, ranging in age from 18 to 40 years, evacuated through the exits to the ground via both platform and slide egress routes. A (2 X 3) repeated-measures, counterbalanced research design was employed to control trial order effects. Analysis of variance revealed overall main effects of egress route ($p<.001$) and exit height ($p<.012$), and a nearly significant interaction of egress route with exit height ($p<.062$). The main effects occurred because the egress onto the platform was much faster than the slide, and egress slowed monotonically as the exit height was reduced. The trend toward an interaction effect of egress route and exit size occurred because reducing the exit height to 48" significantly slowed egress onto the inflatable escape slide ($p<0.017$) but not the platform ($p<.41$). This discriminative effect resulted from the hesitation that subjects displayed when using the slide, relative to the platform, especially at the shortest exit size studied. The increased egress time onto the escape slide appeared to result from a more difficult entry onto the slide, as the lower door heights required subjects to bend over more to enter the slide. This made the typical "jump-and-slide" maneuver much harder to perform. Egress ratings for exits that conform to the dimensions used in this study should reflect these findings, especially when escape slides are the likely egress route.

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Aircraft Evacuations onto Escape Slides and Platforms II: Effects of Exit Size

INTRODUCTION

In a prior report, McLean, George, Funkhouser & Chittum (1996) described the effects of manipulating passenger motivation levels during aircraft evacuations conducted through Type-I floor-level transport category aircraft (airliner) exits. In that study passengers deplaned onto both an inflatable escape slide and doorsill-height platform scaffolding attached to the Aircraft Cabin Evacuation Facility (ACEF) at the Federal Aviation Administration's Civil Aeromedical Institute (CAMI).

Those experimental treatments had been chosen because: 1) differences in passenger motivation levels had been found to be associated with significant differences in passenger behavior during simulated aircraft evacuations (e.g., Muir, Marrison, & Evans, 1989; McLean, Chittum, Funkhouser, Fairlie, & Folk, 1992), and 2) doorsill-height platforms had been used as the escape route in a 1992 full-scale evacuation demonstration conducted to support a Code of Federal Regulations (CFR) § 25.803 analysis for certification of the McDonnell Douglas MD-11 airplane.

In the MD-11 demonstration the time for completion of the aircraft evacuation conducted onto the platforms was significantly reduced, compared with the time for evacuation of the same MD-11 airplane when passengers egressed onto the inflatable escape slides. Importantly, doorsill-height platforms had also been used in some of the motivational research paradigms used to study passenger evacuation behavior (see Muir et al., 1989; Muir, Bottomley, & Hall, 1992).

The differences in the results of those independent activities had made comparative interpretation of the associated findings difficult; the use of a single evacuation facility fitted with both an inflatable escape slide and a doorsill-height platform to further study aircraft evacuation performance was intended to allow better explanations of those differences.

The results of the first study (McLean et al., 1996) were instructional, as the previously established effects on egress of using doorsill-height platforms, as compared with inflatable escape slides, were replicated. Additionally, discriminative effects of high and low passenger motivation levels were found. When combined, however, the effects suggested a complex relationship controlled in part by forces additional to the motivation and egress route treatments, indicating a need for further investigation.

The study reported here was designed to address this need, studying the effects of differences in exit size (height of the opening) on egress using both escape routes. Exit size was chosen as an experimental treatment for two reasons. First, the increased ergonomic requirements attendant to egress at shorter exit heights were expected to provide additional discriminative value regarding differences in evacuation performance onto inflatable escape slides versus doorsill height platforms. Second, there were relatively few research data on 2 new types of floor-level exits that have been certificated for use on transport category aircraft.

Following the MD-11 full-scale demonstrations and the McLean et al. (1996) study, it was hypothesized that egress onto the doorsill-height platform would be generally faster than that onto the inflatable escape slide, owing to both the ease of egress onto the floor-level platform, versus the descending escape slide, and the general hesitancy found when evacuees are faced with using inflatable escape slides. Such a finding would be the second replication of the initial effect found. Prior evacuations through the floor-level exit onto the platform has been shown to be equivalent to walking or running through a typical door from one room to another in a building, whereas egress onto steeply descending escape slides has generally caused evacuees to either sit before sliding, to *gather* themselves in preparation for jumping onto the slide, or to hesitate to use the slide in any fashion. The smaller exit sizes were expected to exacerbate these effects, as mounting the escape slide through shorter exit openings was theorized to be psychologically more challenging and physically more difficult. Thus, an interaction effect of exit height and escape route was expected.

The knowledge to be gained in the study was intended to prove informative for two purposes: 1) the use of exit size to further probe the experimental effects related to egress means (escape slides versus doorsill-height platforms) would enhance the evaluation of diverse aircraft evacuation data, and 2) direct examination of the different exit sizes would significantly expand knowledge relevant to egress and aircraft evacuations through the newly certificated exit types. A final benefit would be to further delimit methodological issues that need to be considered in research designs related to questions about current and future aircraft evacuation systems and procedures.

METHODS

Subjects. The subjects in this experiment were 174 human adults between 18 and 40 years of age. They were divided among 5 experimental groups; Table 1 provides demographics for each group.

Subjects were required to wear long-sleeved shirts and long pants, as well as low, flat-heeled shoes. They were also naive about, and had never participated in, emergency aircraft evacuations.

Design. A 2 (egress route) X 3 (exit height) repeated-measures, research design was employed in the study. Egress route (platform or slide) and exit height (48, 60, 72 inches) were counter-balanced across evacuation trials, providing 6 subject groups using 6 different trial orders. However, several subject injuries occurred near the end of the study. A resultant review of the project suggested that the completed trials had answered the experimental question satisfactorily; thus, the study was truncated after the 5th group had completed its trial series. Table 2 displays the completed experimental design.

Apparatus. The ACEF was configured as a B-737, with rows of triple seat assemblies placed 6 abreast in the cabin. The ACEF was raised to position the floor at the nominal doorsill height of 8 feet 9 inches above the ground. A 72-inch x 30-inch Type-I exit located forward of all seats was fitted with an inflatable single lane slide attached to the exit threshold by a typical girt bar. Foam-rubber tumbling pads were placed on a net positioned directly underneath and around the slide to protect against injury from inadvertent falls (see Figure 1).

Across the fuselage, another 72-inch x 30- inch Type-I exit provided egress onto a 20- x 20- foot square doorsill-height platform, which transitioned to the ground via a 10 foot-wide, 35 foot-long ramp extending from the platform directly perpendicular to the exit and declined at a 15 degree angle (see Figure 2). Both exits were modified to allow placement of removable plugs at the top of the exit opening by which to reduce exit height to 60 or 48 inches. Both exits were also covered with fabric curtains (simulated doors) that were individually removed, as appropriate to the experimental condition, immediately upon the sounding of the start buzzer at the beginning of each trial. These coverings were intended to prevent subjects from viewing the exit opening size before the trial began. Bulkheads with a 30-inch opening at the aisle were also situated in front of the seat rows to further impair direct view of the exit. Video cameras with timing capability were situated parallel to the fuselage at the exits to archive the evacuation data. During all trials the ACEF was maintained at the CFR 25.812 minimum 0.05 foot-candle emergency interior lighting level.

Table 1. Subject Attributes

GROUP	AGE (yrs)	WEIGHT (lbs)	HEIGHT (ins)	GENDER M	GENDER F	TOTAL SUBJECTS
1	18-40	105-257	62-76	18	18	36
2	18-40	108-233	62-75	17	17	34
3	18-39	96-263	63-80	22	12	34
4	18-39	98-264	61-75	21	15	36
5	18-39	119-275	61-78	25	9	34
TOTALS				103	71	174

Table 2. Experimental Design

GROUP	EXPERIMENTAL TRIAL SERIES					
1	P48	S60	P72	S48	P60	S72
2	P60	S72	P48	S60	P72	S48
3	P72	S48	P60	S72	P48	S60
4	S48	P72	S60	P48	S72	P60
5	S60	P48	S72	P60	S48	P72

* P = Platform; S = Inflatable slide; Exit height = 48, 60, or 72 inches

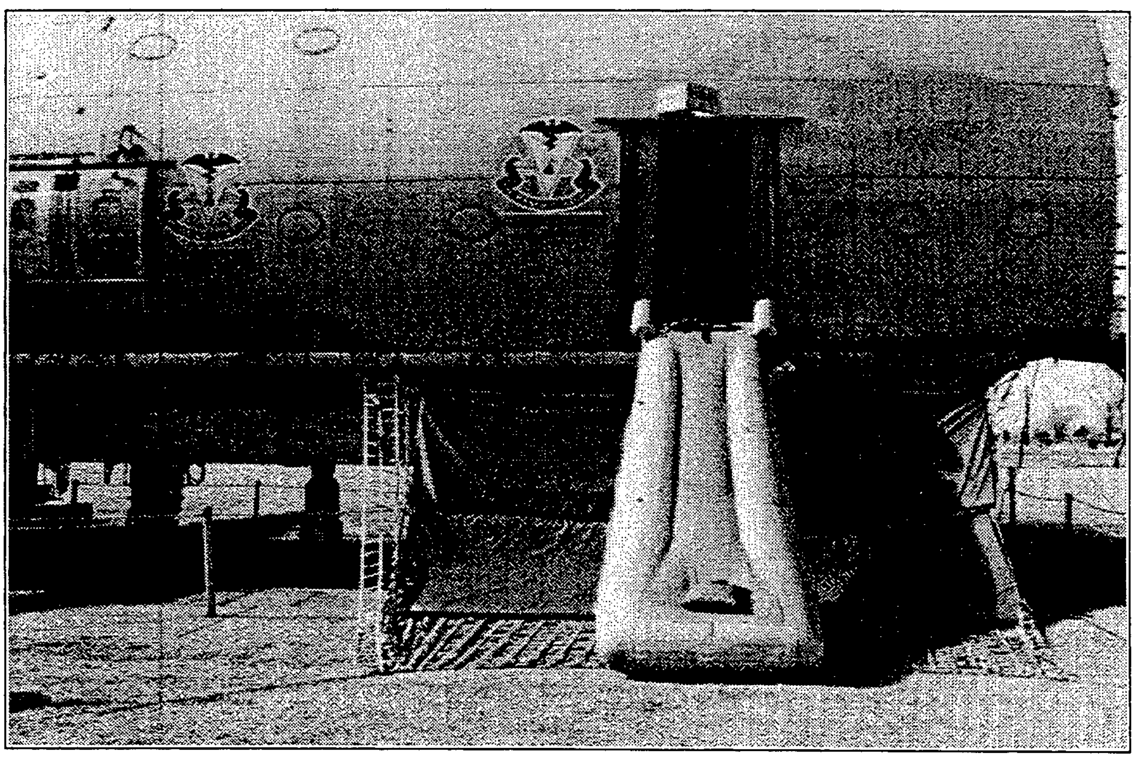

Figure 1. Slide Egress Route

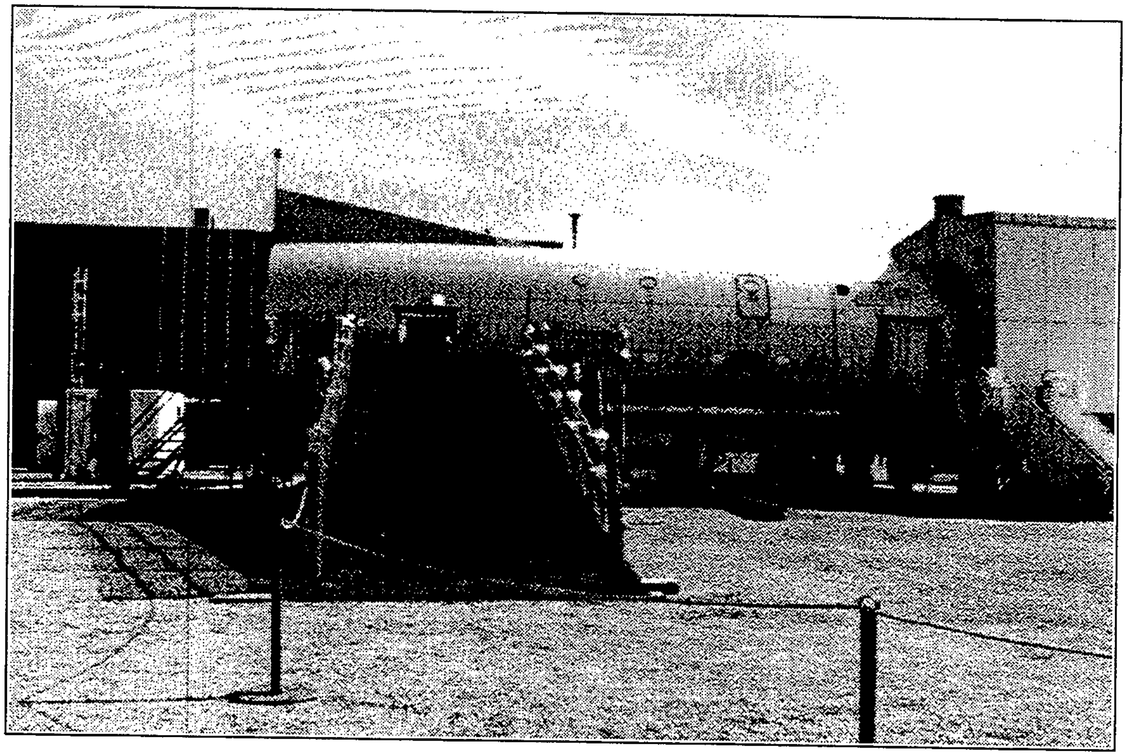

Figure 2. Platform Egress Route

An active-duty airline flight attendant was stationed at the active Type-I exit to remove the exit covering and to encourage and assist subjects, as needed. A second flight attendant was stationed across the cabin at the inactive Type-I exit to block subject flow through that exit and redirect any straying subjects toward the active exit. The same 2 flight attendants were employed throughout the study; both were required to serve as the active-exit attendant. Other members of the research team were located at the end of the slide or the inclined ramp to assist subjects and to guide them away from the exit area after they had deplaned. Medical personnel were also in attendance in the event of injury.

Motivation. Subjects were instructed that the evacuations were intended to simulate actual emergencies, and that they should egress as fast as possible. At the start of each trial, the flight attendant at the active exit would shout commands to unbuckle seat belts and come forward to the exit. The active-exit flight attendant continued to shout evacuation commands and gesture enthusiastically (per airline training) throughout every trial; the other flight attendant redirected straying subjects to the active exit.

Procedure. Prospective subjects were given a general explanation of the purpose of the study and detailed information about the procedures to be used. Visual information and briefings about how to use the inflatable escape slide were also provided prior to the subjects giving informed consent.

Once entered into the study, subjects also completed a personal demographics questionnaire, and had their height, weight, and waist size noted for anthropometric analysis. They were then escorted to the ACEF to become visually familiar with the egress systems and to prepare for the trials. The subjects were issued boarding cards with random seat assignments, and they seated themselves accordingly.

After the briefings describing the experiment were read, they were allowed to ask additional questions. When these activities were completed and the subjects indicated their readiness, the principal investigator exited the cabin to avoid interference with the trial. The buzzer used to indicate the beginning of the trial was sounded after some variable interval of 30 seconds or less.

At the start of the trial, the 2 flight attendants were stationed at the front of the cabin, 1 by each of the Type-I exits. Immediately upon the sound of the buzzer, the curtain covering the active exit was removed by the associated flight attendant, who then began shouting and gesturing for the subjects to unbuckle their seatbelts and proceed through the exit. After the evacuation trial was completed, subjects were re-grouped, given new random seating assignments, and boarded for the next trial.

RESULTS

The videotape recordings of each trial were examined to obtain total evacuation times, which were analyzed using *SPSS for Windows®*, version 6. Total evacuation time was defined as beginning at the time the start buzzer initially sounded and lasting until the 28th subject had cleared the Type-I exit opening. The reduction in analyzed group size (as compared with the subject group sizes listed in Table 1) occurred because one of the groups incurred the bulk of the injuries mentioned above. The other group data were truncated to allow appropriate statistical comparisons. A 2-way (egress route x exit opening size) repeated-measures analysis of variance found a within-group main effect of egress route ($p < .001$; Figure 3) and a within-group main effect of exit size ($p < .012$; Figure 4). The interaction of egress route with exit size produced a nearly significant trend ($p<.062$; Figure 5) that may have achieved significance had the study design not been truncated.

A simple effects analysis found this trend to result from a within-group effect of exit size produced when subjects used the inflatable slide ($p < .017$) but not the platform ($p < .41$). This effect appeared to result from the effects of subject hesitation at the exit fitted with the slide, coupled with the increased ergonomic demands of entering the slide, especially at the lesser exit heights. These effects reveal the strong role that egress route had on the evacuations, particularly when the exit sizes were reduced.

DISCUSSION

The effects of egress route on evacuation rates were shown to be significant, as the doorsill-height platform allowed much faster evacuations than the inflatable slide. Subject hesitation at the exit fitted with the slide was the governing principle for this effect; egress onto the platform was equivalent to going unimpeded (except for the exit height-reducing plug) from one room through a door into another room in a building. In contrast, use of the slide required sitting, with its need for additional behavioral preparation, or a downward leap onto the slide surface, which required both behavioral and psychological preparation. As also seen in McLean et al. (1996), having to jump onto the slide produced individual subject hesitations before many of the subjects would jump;

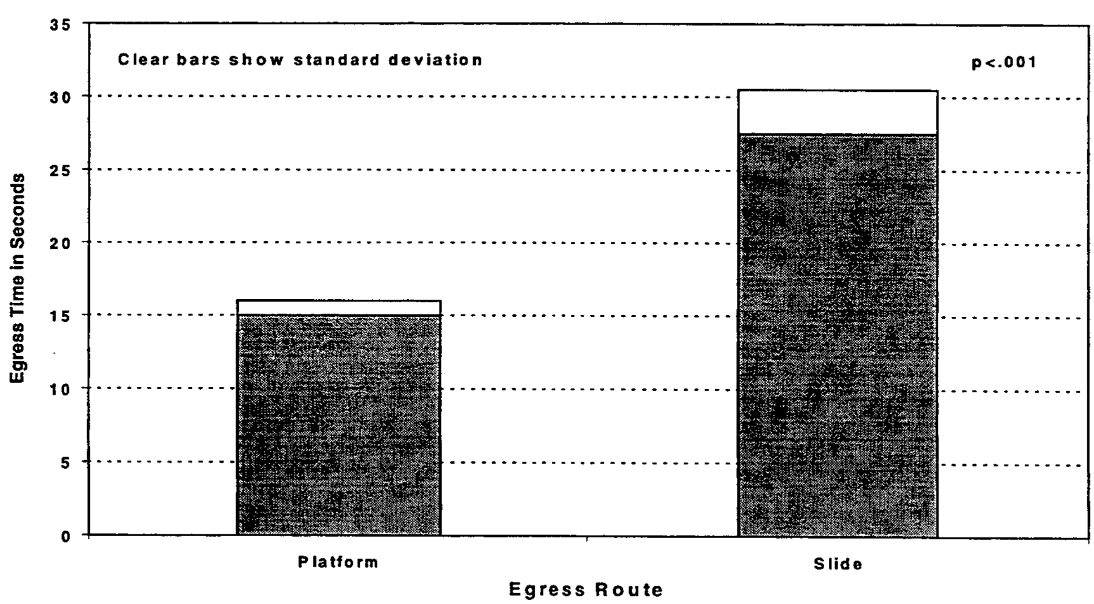

Figure 3. Main Effect of Egress Route

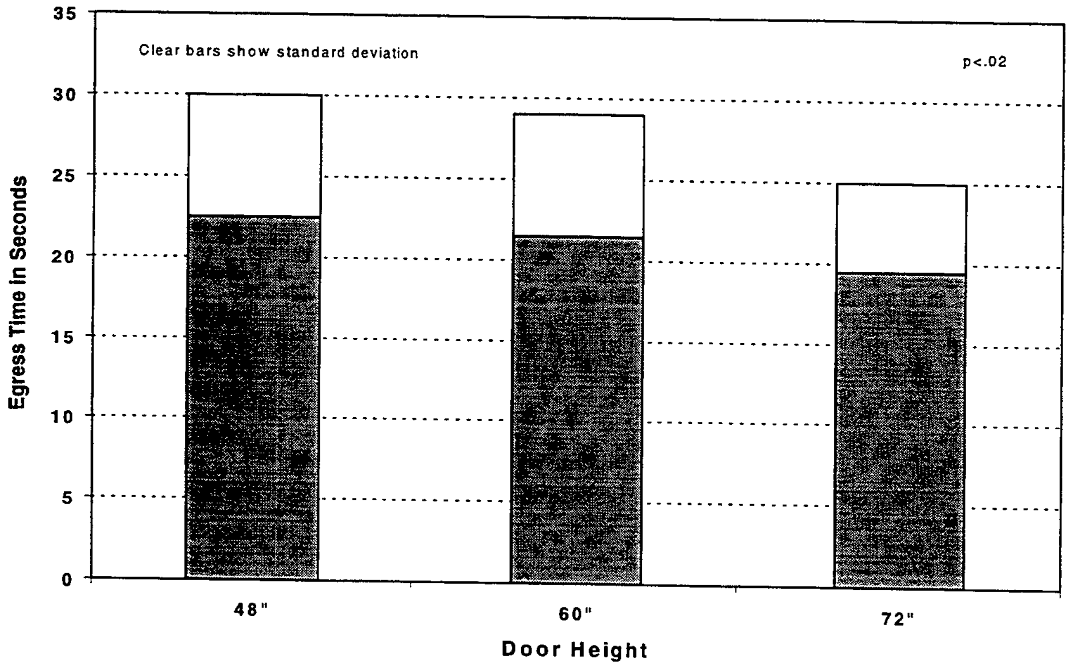

Figure 4. Main Effect of Exit Size

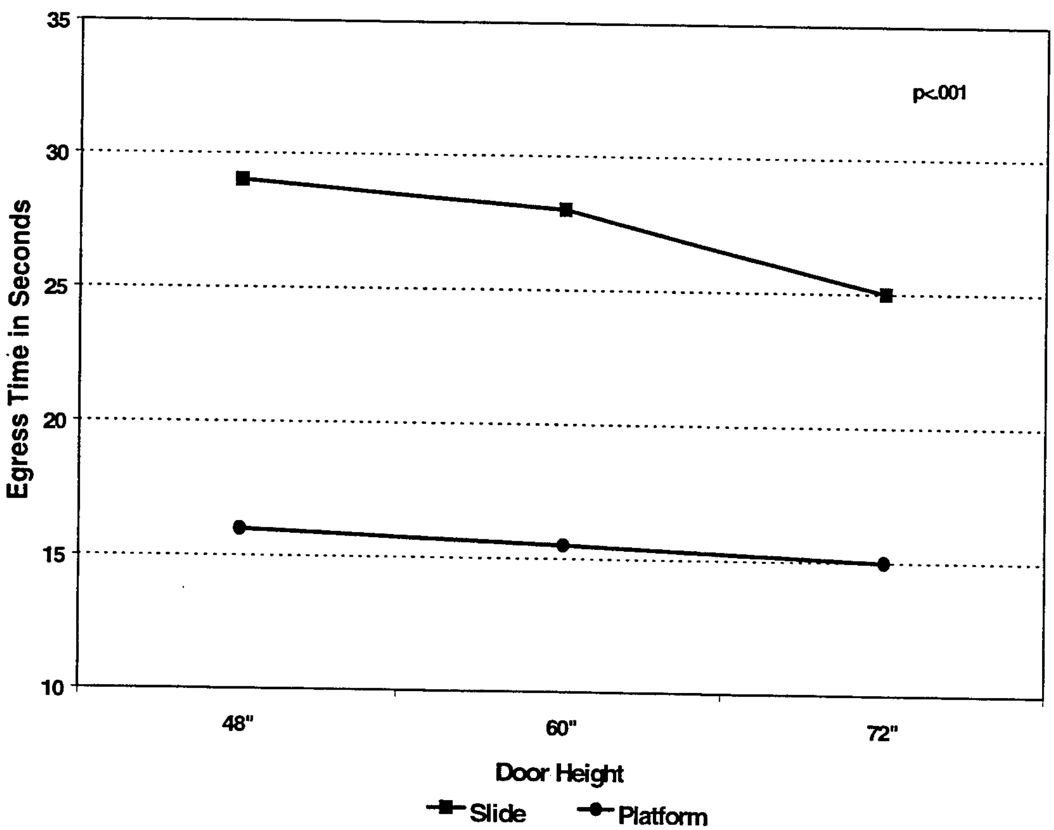

Figure 5. Interaction Effect of Egress Route and Exit Size

the cumulative effects of the behavioral adjustments and these added hesitations were responsible for the main effect of egress route seen.

The effects of reducing exit height were also shown to be significant, as the 48-inch high exit produced significantly lower evacuation rates, as compared with both the 60- and 72- inch exit sizes. However, this effect was essentially limited to egress onto the escape slide, and appeared to result from the increased ergonomic difficulty of having to bend over before jumping onto the slide. The statistical trend seen toward a hyperadditive interaction of egress route and exit size affirms this added difficulty, as does the main effect of exit height when evacuees used the slide but not the platform. In summary, as the exit height was reduced, egress onto the slide slowed significantly; in contrast, rates onto the platform remained consistent for all exit heights.

The lack of exit size effects when using the doorsill-height platform occurred because the behavioral and psychological demands of the platform did not compare well with those of the escape slide. Evacuees were simply not as challenged as they were when using the slide. Thus, the doorsill-height platform masked the effects produced by reducing the exit size, thereby limiting its own acceptability as a research tool in evacuation studies. Proposed use of this type of egress means should be examined closely for validity.

These effects indicate that, in general, the type of egress means employed in experimental evacuations is important to the results obtained. In particular, platforms, egress ramps, flaps, escape slides with odd geometry's, and/or other means of egress different from current escape slides could all be expected to generate differential effects on egress. This implies that evacuation results obtained with one type of egress means should not be casually generalized to any other.

In addition to these considerations, several other variables are likely to be important to evacuation results, even when the evacuations are conducted through floor-level exits onto escape slides. Extremely tall doorsills, very long escape slides, extreme descent angles, emergency lighting system differences (when appropriate), and variances in crew procedures are also likely to be important considerations. Thus, results obtained with one type of escape slide should not necessarily be generalized to another escape slide.

Together, these findings confirm that specific aspects of the egress route utilized in any aircraft evacuation study are important contributors to the results evidenced. The physical and psychological demands attendant to any particular egress means appear to impact the results substantially, rendering interpretation of the results difficult without appreciation of those associated demands.

When combined with the results found by McLean et al. (1996), it becomes clear that evaluations of future aircraft designs and evacuation systems, especially those that differ significantly from the systems in use today, will require careful attention to the apparatus and procedures used, in order to assure that the results are valid and reliable.

Studies designed to model evacuations of a specific aircraft should use that aircraft's actual evacuation means to obtain the highest fidelity possible. Similarly, studies intended to answer general questions about the consequences of specific factors on egress must be carefully controlled to assure that the results can be interpreted adequately and generalized appropriately. As a corollary, the use of special apparatus or procedures to demonstrate compliance with regulatory requirements should be carefully weighed.

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