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Human Factors Associated With the Certification of
Airplane Passenger Seats: Life Vest Retrieval

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Washington, DC 20591

# Human Factors Associated With the Certification of Airplane Passenger Seats: Life Preserver Retrieval

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16. Abstract

A series of human subject tests were conducted by the Biodynamics Research Team at the FAA's Civil Aerospace Medical Institute (CAMI) to investigate human factors associated with the "easy reach" requirement in FAA regulations for under-seat mounted life preservers. The protocol was designed to observe and measure the effects of human physical attributes and life preserver installation features relevant to the retrieval of life preservers. A mockup of a 30-inch pitch, economy class transport passenger seat installation was used to evaluate 4 configurations of life preserver installations. The position of the pull-strap, used to open the life preserver container, was the independent variable.

One hundred thirty-two adult subjects were tested. Each subject was seated, restrained by the seat's lap belts, instructed to reach beneath the seat, open the lifer preserver container, and extract the packaged life preserver. The time for retrieval of the life vest was measured from videotapes of each test. The videotapes were also reviewed independently by 11 outside raters, who rated the difficulty for each subject on a scale of 1 (easy) to 7 (very difficult).

There was significant agreement (Cronbach's alpha = 0.978) in the "ease" ratings. In comparing the ease ratings and retrieval times, an average ease rating < 3 corresponded to a retrieval time < 10 seconds. An "EASY10" benchmark, derived from these results, indicates that a life preserver retrieval time < 10 seconds should be considered easy. Two of the configurations had average ratings < 3. The installation features that distinguish the two configurations that passed the EASY10 benchmark, compared with the two that failed, were the position of the pull-strap, the pull-angle on the strap necessary to effect a quick opening of the life preserver container, and the position of the stowed life preserver relative to the front frame of the seat.

The results indicate that the "easy reach" criteria should be satisfied if: 1) the pull-strap and life preserver container are no more than 3-inches aft of the seat frame, and 2) the pull-angle to quickly open the container is in the range: $-50° < \theta < -10°$.

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# Human Factors Associated With the Certification of Airplane Passenger Seats: Life Preserver Retrieval

## INTRODUCTION

Compliance with FAA regulations for personal floatation devices, e.g. inflatable life preservers, installed on transport airplane passenger seats includes three important factors. First, the design and functional performance of the life preserver is specified in TSO C13 (1). Second, the physical containment and mounting of the life preserver, commonly on the underside of the seat pan, is the responsibility of the seat manufacturer to ensure that the life preserver and container are properly attached to the seat. The third factor is the access to the life preserver, evaluation of which is usually performed during final inspection of the cabin interior prior to approval for delivery of the airplane into service.

The FAA regulation addressing life preserver installations specifies: "Each life preserver must be within easy reach of each seated occupant" (2). There are no published FAA guidance or policy documents to define the term "easy reach" in this regulation. Nor is there any implication regarding the range of occupants (e.g. body size) that should be able to reach the life preserver easily. Thus, the pass/fail assessment of life preserver installation, based on the judgement of the approving official, is subjective and potentially inconsistent.

A previous study (3) of systematic human performance related to airplane passenger life preservers focused on retrieval time, donning time, and donning errors for different types of life preservers installed at two different locations on a passenger seat. A comparison of preserver retrieval times for two different stowage locations, beneath the seat versus the seat-back, was reported in this earlier study (beneath seat: mean = 17.0 seconds, SD = 10.7; seat-back: mean = 13.6 seconds, SD = 6.2). The differences in retrieval times were not statistically significant. Although retrieval time can be an indicator for ease-of-effort, other factors, including human anthropometry and the physical design/installation of the seat and preserver container, may affect the ease of retrieval.

A series of human subject tests were conducted by the Biodynamics Research Team at FAA's Civil Aerospace Medical Institute (CAMI) to investigate the human factors affecting the "easy reach" requirement for under-seat mounted life preservers. The protocol, which included a mockup of a passenger seat installed in an economy class transport cabin configuration, was designed to allow observation and measurement of the effects of human physical attributes and life preserver installation features associated with the ease of retrieval. The data and observations acquired from this effort were analyzed to evaluate the key features that influence the ease of retrieval of an under-seat life preserver. Examined were the relationships between subjects' physical measurements, container/preserver location, time to retrieve a preserver, and a subjective ranking of "ease-of-retrieval."


**Figure 1**. Test Setup

## DESCRIPTION OF LIFE PRESERVER RETRIEVAL TESTS

**Test Setup**. As shown in Figure 1, two typical economy class passenger seats were installed on a test fixture to represent the geometry of a 30-inch seat-pitch installation. The seat-to-seat dimensions are illustrated in Figure 2. The 30-inch seat-pitch, which is in the narrow range for contemporary US domestic carriers, was considered conservative for assessing installation effects on preserver retrieval. The rear seat was offset to the right by one seating position, as

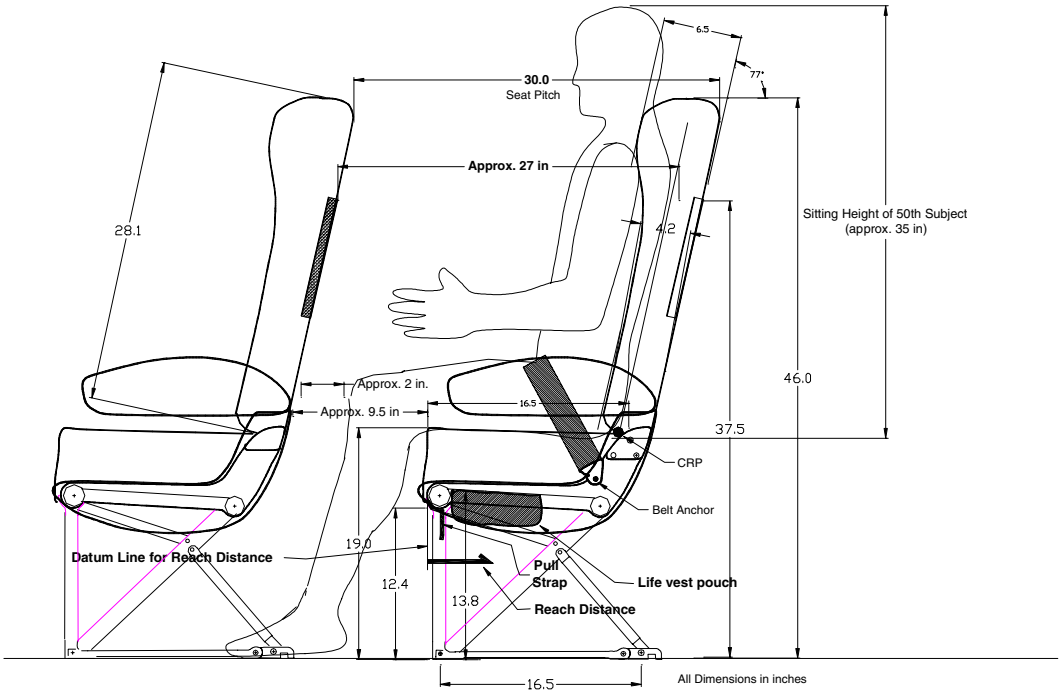


**Figure 2**. Setup Dimensions

shown in the overview of the test setup (Figure 3). This lateral offset between the forward and rear seats provided ample video camera coverage of the motion of the subjects seated in the aft seat during life preserver retrieval, and it prevented the subject from leaning forward into the "aisle space" left of the forward row seat. Seat-back breakover features on the seats were locked to inhibit forward motion of the seat-backs, and the armrests on the subject-occupied rear seat were placed in the down position.

**Video Coverage and Instrumentation**. Two NTSC video cameras were positioned on the side of the test setup to cover the subject's motion. As illustrated in Figure 3, one video camera view was framed to record the overall test setup, and the other camera focused on a close-up view of the underside of the subject-occupied seat. Two red light-emitting diodes (LEDs), one mounted on the top of the seat-back in front of the subject and one mounted in the rear base frame tube of the forward row seat, served as "start test" indicators and for synchronization between the cameras. The seat-back LED provided the start stimulus for the test subject, and the base frame LED was recorded in the views of both cameras. The test conductor initiated each test by pressing a switch that simultaneously illuminated the two LEDs, signaling the subject to retrieve the life preserver.

Retrieval time was measured using the under seat close-up video tape by counting the number of video frames (recorded at 30/sec.) between the start LED illumination and the first video frame showing complete removal of the life preserver from the container by the subject. The close-up under-seat video was also used to estimate (± 5°) the pull angle on the release strap, which provided the means to open the front flap on the container and gain access to the packaged life preserver as the subjects attempted to open the container.

A device to measure each subject's sitting height and under-seat reach distance was mounted behind the rear seat. Subject weight, standing height, and waist girth measurements were recorded prior to the tests, along with gender, age, and education information. These data were included in the analysis of the results.

**Life Preserver Container Configurations**. The primary variable for the life preserver installation was the location of the release strap. There were four configurations of release strap position, as illustrated in Figure 4. The position of the release strap varied relative to the front edge of the main lateral tube on front of the seat frame. Although these four configurations do not encompass the entire range of designs and installations used on contemporary passenger seats, the key parameters related to the location of the release strap on the container were typical of those installed on current seat models.

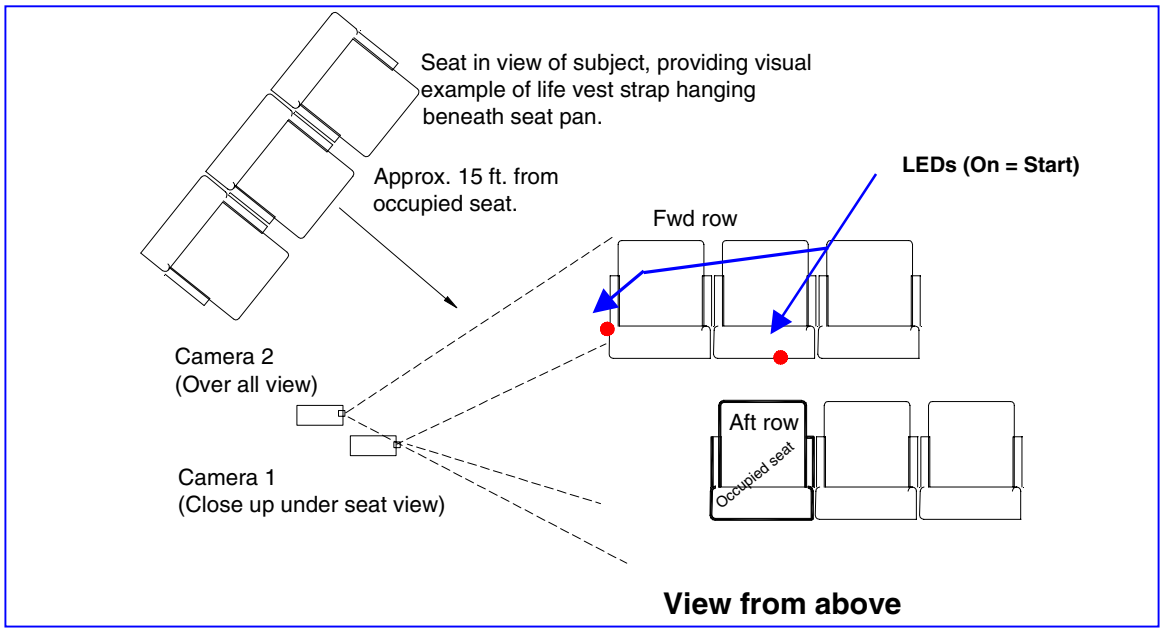


**Figure 3**. Overview of Test Setup, Viewed From Above

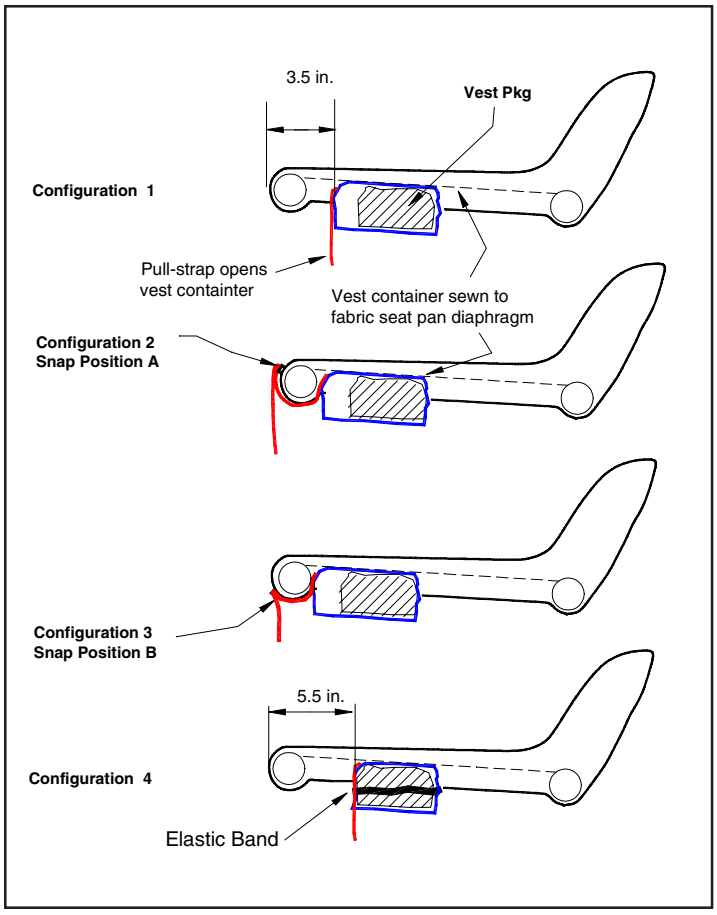


**Figure 4**. The Four Life Preserver /Container Configurations

The following summarizes the installation features for each of the four configurations, along with general observations made during tests:

**Configuration 1**. (Figure 5)

• The release strap snaps to a mating stud on the nylon container.

• When the container is closed, the release strap hangs vertically approximately 3.5 inches behind the front edge of the seat frame (formed by a lateral tubular beam).

**Configuration 2**. (Figure 6)

• The release strap snaps to a mating stud located near the top (11 0'clock) on the forward side of the front tubular beam. The mating snap stud is attached to the front flap of the nylon seat pan diaphragm, which wraps around the front tubular beam.

• When the container is closed, the release strap drapes over the front beam and hangs vertically, tangent to the front tubular beam. The seat cushion bears on the release strap snap.

**Configuration 3.** (Figure 7)

• This installation is similar to that of Configuration 2, except the release snap mating stud is located towards the bottom (8 0'clock) on the forward side of the front tubular beam.

• When the container is closed, the release strap hangs vertically from the lower front side of the tubular beam. The seat cushion does not bear on the release strap snap.

**Configuration 4**. (Figure 8)

• This configuration was the same as Configuration 1, except a rubber band was wrapped around the nylon container and release strap to move the release strap rearward. When the container flap was closed, the release strap was approximately 5.5 inches behind the front edge of the seat frame.

• In this configuration, the plastic bag containing the life preserver was purposefully shoved to the rear of the container. This increased the distance a subject had to reach to grasp and remove the life preserver.

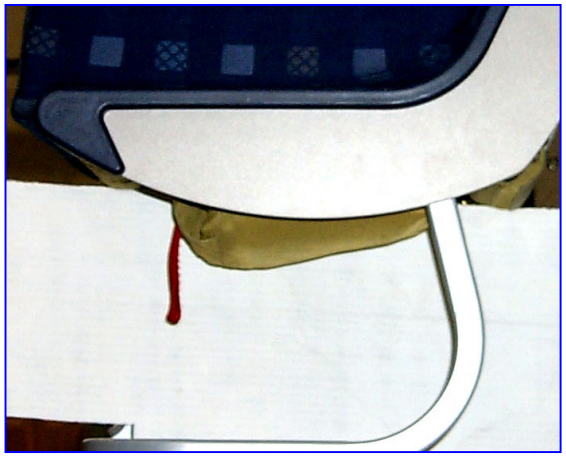

**Figure 5**. Configuration 1

**Figure 6.** Configuration 2

**Figure 7**. Configuration 3

**Figure 8**. Configuration 4

**Table 1.** Subjects' Physical Data

| | | Weight (lbs) | | Stature (in) | | Waist (in) | | * Sitting Height (in) | | **Under-Seat Grasp (in) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Males | 70 | 231 | 51 | (72.2) | 3.1 | 42 | 6.8 | 34.4 | 1.5 | 5.2 | (3.1) |
| Females | 64 | 170 | 47 | (64.9) | 2.7 | 35 | 6.1 | 31.6 | 1.4 | 5.9 | (3.1) |

Note: All measurements were made with the subjects fully clothed and wearing shoes, which added to the weight, stature, and waist measurements.

* Sitting height measured vertically from the top of subject's head to horizontal plane through the seat cushion reference point

** Under-Seat Grasp estimated as 2 inches less than the maximum under seat reach of extended finger tips.

The measured pull force to extract the plastic package containing the life preserver from the nylon container in all four configurations was 4 to 5 pounds.

**Subject Selection**. The human subjects for this study were participating in a concurrent research activity at CAMI related to emergency egress. The subjects for the life preserver retrieval study, comprised of 132 healthy adults between the ages of 18 and 65 years, were selected from the pool of subjects in the egress research project. In addition to "average" size subjects selected randomly from the pool, small females and large males were deliberately picked from the groups of people arriving for the egress study. The rational for selection of specific small female and large male subjects in the life preserver retrieval study was based on assumptions that data from subjects in these two physical ranges would likely bound the performance characteristics of the general population.

Physical data for the subjects in this study are summarized in Table 1. There was no attempt to categorize anthropomorphic percentile ranges for the subjects. The average weight for the male subjects, 231 lbs., is a consequence of deliberate selection of large males from the subject pool. Figure 9 depicts the weight and stature for all male and female subjects in this study compared with the ranges in the general population used to define anthropometric characteristics for regulated test dummies (4). Figure 9 shows that the average weight of the male subjects participating in these tests is greater than the average weight of the normal US male population.

**Protocol.** Each subject was directed to sit in the aft row test seat and buckle the lap belts as if in preparation for take-off or landing. Next, a verbal description

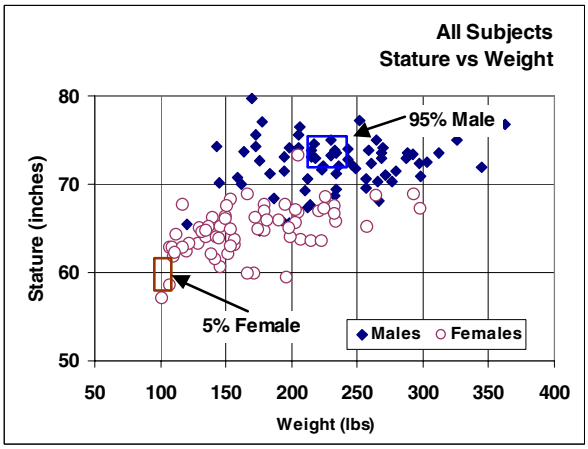


**Figure 9.** All Subjects' Physical Size

of the purpose of the test and the instructions for performing the test were read to the subject. The instructions were as follows:

> The purpose of this experiment is to evaluate the ease or difficulty passengers traveling in an airplane may have with the retrieval of the life vest underneath their seat.
>
> In this experiment, we ask you to perform the following actions: With your seat belt buckled and your arms resting on your lap, observe this small red light on the seat in front of you. When you see the light turn on, lean forward without removing your lap belt, reach under the seat you are sitting in, and pull on the strap hanging down under your seat to open the life vest pouch.

*(At this point of the instructions, the test conductor directs the subject's attention to a passenger seat in the view of the subject, approximately 12 feet away. The test conductor tells the subject there is a strap under his/her seat similar to the one in view on the other seat.)*

Reach into the open pouch and pull out the life vest, which is in a plastic package. Then, sit upright in your seat with the life vest in your lap. Do not open or try to put on the life vest. This is not a timed event, so you do not have to be in a big hurry.

Thus, when the light turns on, keep your seat belt buckled, reach beneath your seat, pull the strap hanging down under the seat, retrieve the life vest, and then sit upright with the vest in your lap. Remember that you do not have to be in a hurry to get the vest.

Each subject was tested once. The motions of a subject attempting to retrieve the preserver were recorded by the video cameras (described above). Measurements of sitting height and under-seat reach distance were made after each test (see Table 1). Note that the sitting height reported in Table 1 is the vertical distance from a horizontal plane through the seat cushion reference point (CRP) to the top of a subject's head. This dimension is illustrated in Figure 2.

## ANALYSIS METHODS

The independent variable for these tests was the container/life preserver location beneath the seat pan. The analysis method included subjective assessments, described below, by a group of 11 raters who evaluated each test subject's efforts to retrieve the life preserver. The ratings were examined to determine relationship between each test subject's efforts and the installation features of the four configurations. The objective of this method was to determine: 1) if there was a general consensus of the reviewers' opinions on the ease/difficulty of preserver retrieval, 2) the features of the container/life preserver locations that were associated with easy or difficult retrieval efforts, and 3) the effects of physical anthropometry on retrieval of the life preserver.

**Subjective Assessment**. Videotapes of all the tests were provided to the 11 raters, who were asked to independently rank the degree of difficulty each of the test subjects experienced retrieving the life vest. The raters included four engineers from airplane seat manufacturers, an interiors engineer from a large airplane manufacturer, a flight attendant, three engineers from FAA aircraft certification offices, and two office secretaries. No rater participated in the conduct of the tests, and the instructions provided to them did not include details describing the installation configurations for specific tests or specific information about the subjects. The ranking method involved assigning a score from 1 (very easy) to 7 (very difficult) for each subject's efforts as viewed on the videotape.

Figure 10 presents the guidelines included in the scoring instructions.The ranked assessment scores were statistically analyzed to determine the degree of consensus among all of the reviewers. Cronbach's Alpha, a reliability analysis, was used to measure the consistency in the reviewers' scores. The computed result (11 reviewers, 132 test scores, alpha = 0.978) indicated there was significant agreement in the ratings, and no single reviewer's scoring of the tests differed significantly from the others.

| SCORE | ASSESSMENT | EXAMPLE OBSERVATIONS |
|---|---|---|
| **1** | **Very Easy** | Subject quickly and easily reached pull-tab, then removed vest in one continuous motion. No delays or difficulties observed. |
| **2** | | |
| **3** | **Easy, with minor difficulty** | Subject successfully reached pull-tab AND removed vest after first attempt. Slight difficulty was observed, such as more than one tug on the pull-tab or more than one attempt to remove the vest package. |
| **4** | | |
| **5** | **Difficult, but successful** | After repeated attempts and/or using different methods to open pouch and/or retrieve vest, the vest was extracted. The subject adjusted his/her "lean-over-posture" or reach path during the test. |
| **6** | | |
| **7** | **Very Difficult** | Subject had great difficulty in reaching pull-tab, OR opening the pouch, OR it took too long to retrieve vest, OR the vest was not retrieved. |

**Figure 10.** Subjective Assessment Ranked Scoring Instructions

## RESULTS

**The EASY10 Criteria**. Figures 11 to 22 and Table 2 present the results of these tests. Although retrieval time was not explicitly identified as a benchmark for scoring the tests by the reviewers, a relationship between the average ranked scores for each life preserver installation configuration and the measured retrieval time was apparent, as shown in Figure 23. A rational (albeit subjective) choice of an "ease assessment" rating of 3 was selected as the demarcation between easy and difficult. This benchmark would place Configurations 1 and 3 in the "easy" range (score < 3). Configurations 2 and 4 would be considered "difficult" (scores > 3). Referring to Figure 23, a score of 3 relates to a retrieval time of approximately 10 seconds. For the purpose of discussing these results, this relationship is identified herein as the *EASY10 criteria*, which suggests an ease assessment score <3 satisfies the "easy reach" requirement in the regulation. Included in Figures 11, 14, 17, and 20 are cumulative percentage results, which show the percentage of subject tests in each of the four configurations that would satisfy this criteria (score < 3). These results are also listed in Table 2.

**Installation Effects**. Although only four configurations were evaluated in this program, the "easy vs. difficult" outcomes from the EASY10 criteria can be applied to specific characteristics that are common to many life preservers installed under the seat-pan. Three characteristics identified in this study are discussed in the following:

**1. Container Location**. The most obvious factor affecting the retrieval of an under-seat life preserver is the ability of the seated occupant to reach under the seat, grasp the release strap, and remove the packaged preserver. The "grasp distance" was determined empirically as two inches less than the measured reach distance, which was defined as the distance

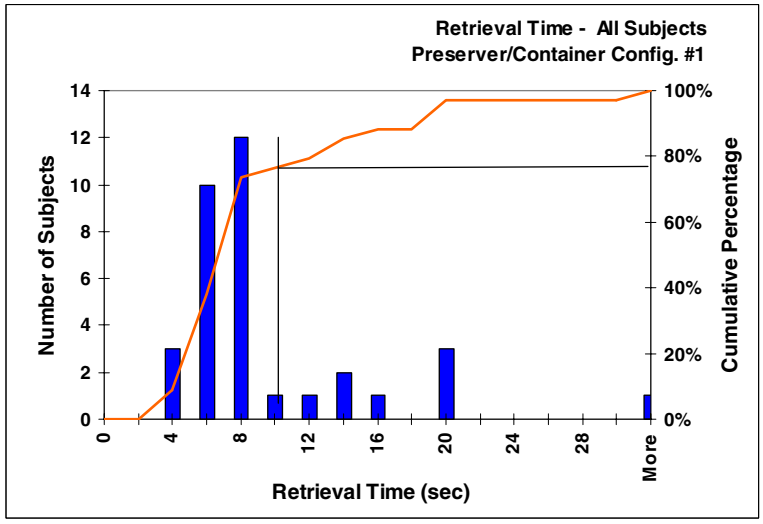


**Figure 11**. Configuration 1 - Retrieval Time

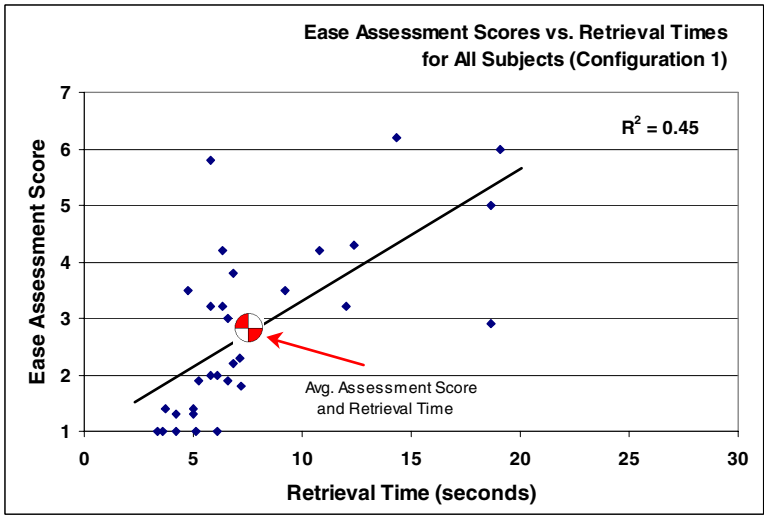


**Figure 12.** Configuration 1 – Ease Assessment Scores vs Retrieval Time

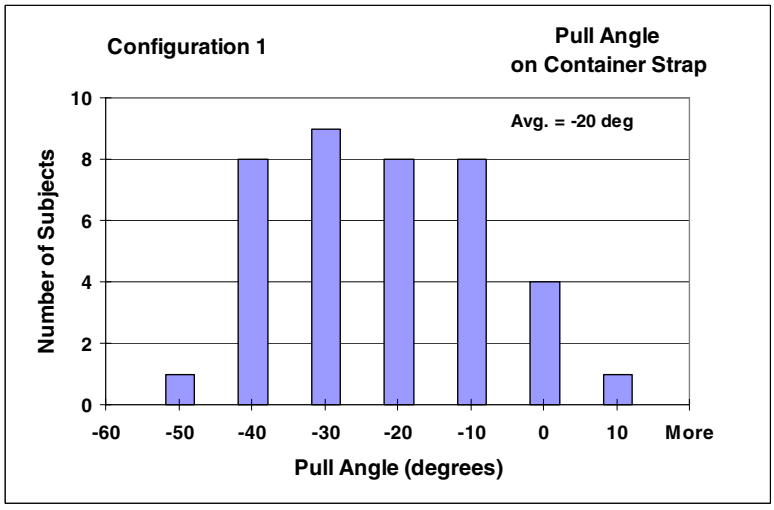


**Figure 13**. Configuration 1 – Pull Angle on Release Strap

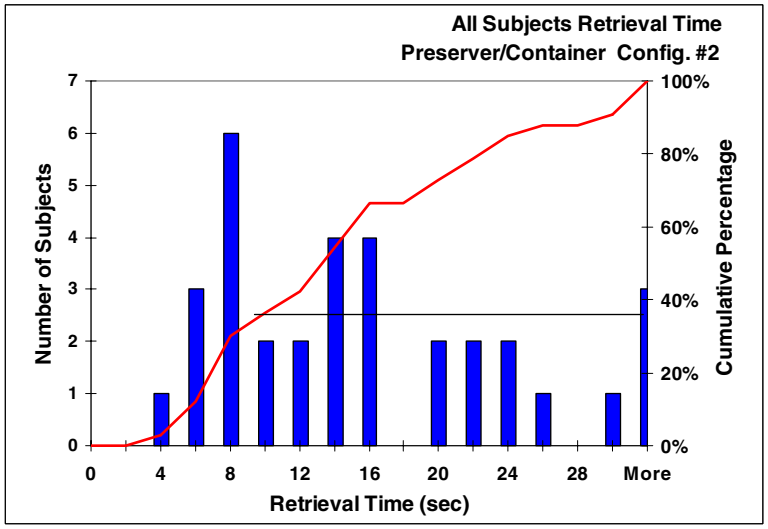


**Figure 14.** Configuration 2 - Retrieval Time

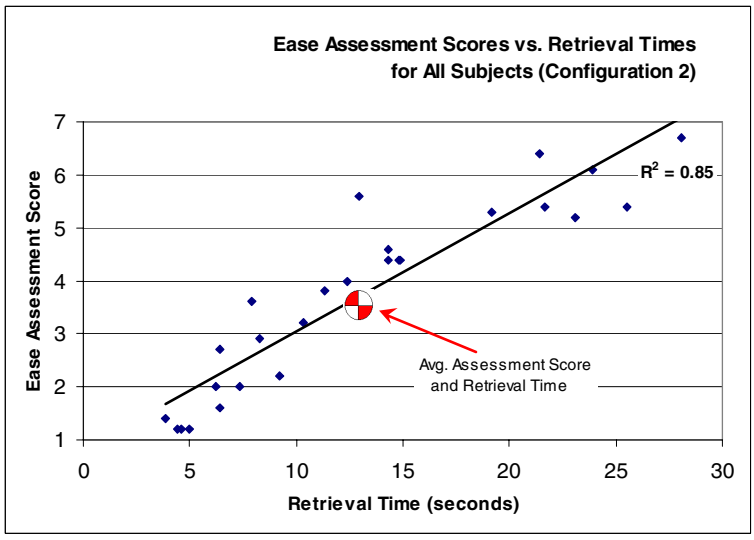


**Figure 15**. Configuration 2. – Ease Assessment Scores vs. Retrieval Time

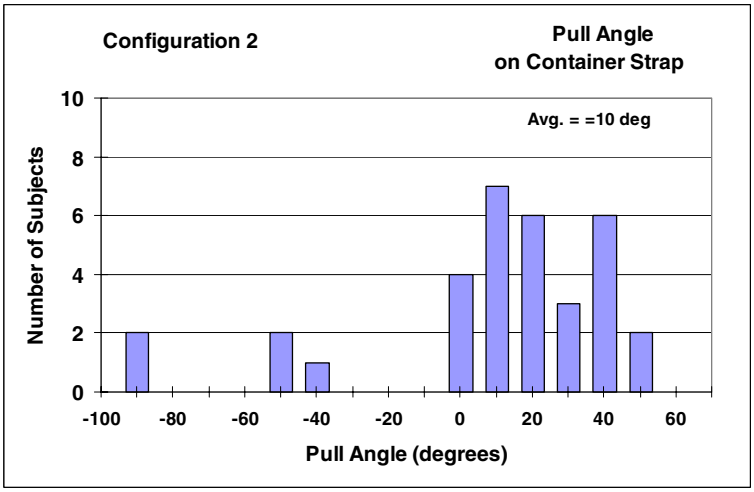


**Figure 16.** Configuration 2. – Pull Angle on Release Strap

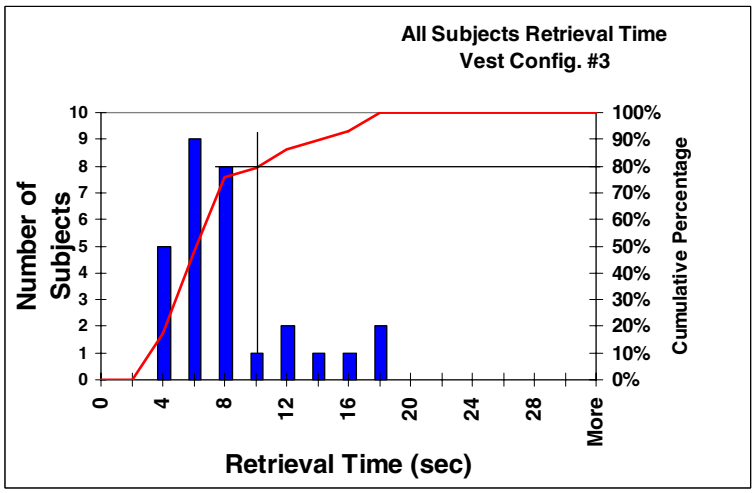


**Figure 17.** Configuration 3 - Retrieval Time

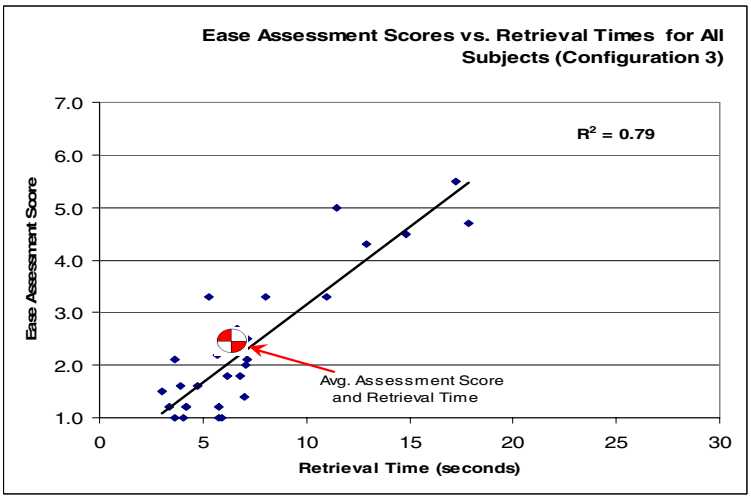


**Figure 18**. Configuration 3. – Ease Assessment Scores vs. Retrieval Time

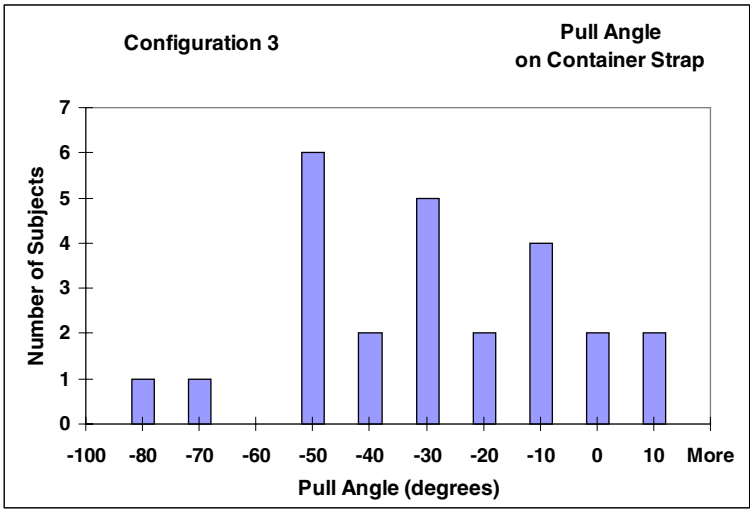


**Figure 19**. Configuration 3. – Pull Angle on Release Strap

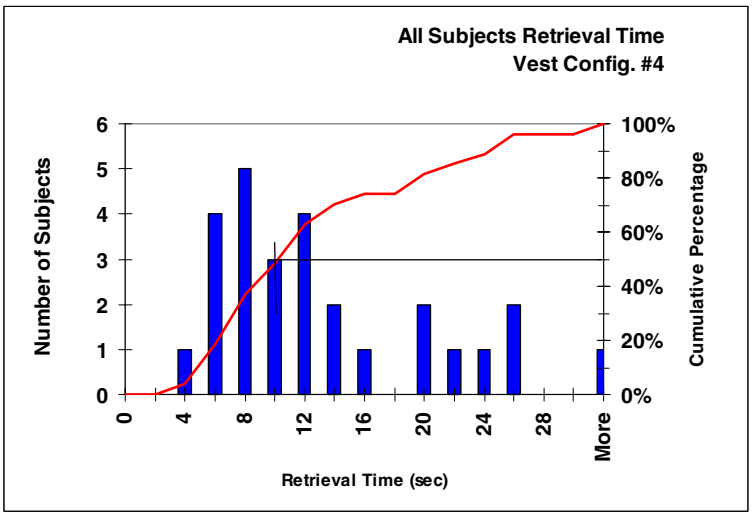


**Figure 20.** Configuration 4 - Retrieval Time

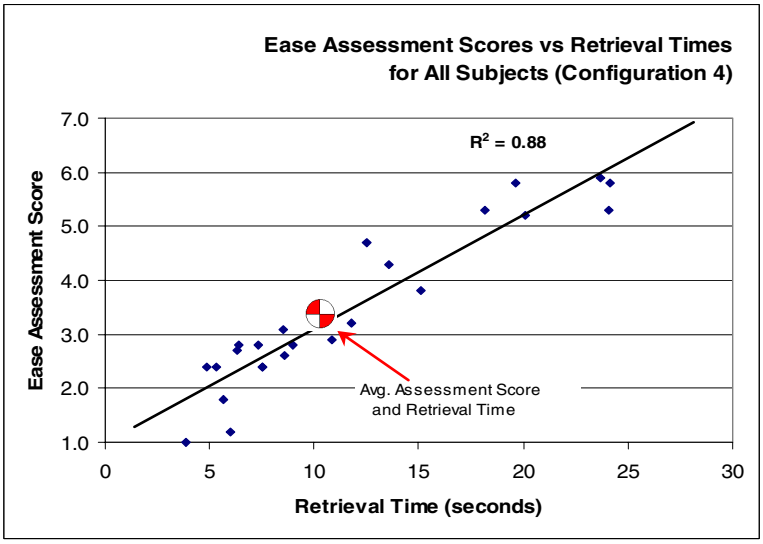


**Figure 21.** Configuration 4 - Ease Assessment Scores vs. Retrieval Time

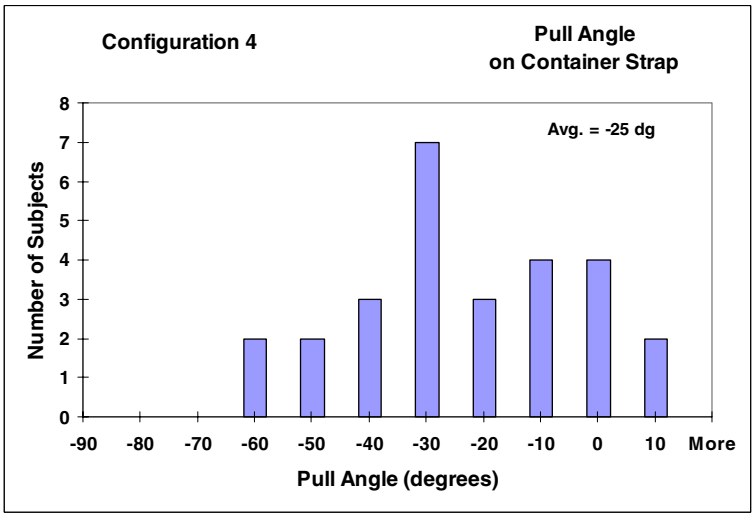


**Figure 22**. Configuration 4 - Pull Angle on Release Strap

**Table 2.** Summary Results

| Container Config. | Subjects | Ease Assessment Avg. Score | | Retrieval Avg. Time (sec.) | | Container Strap Avg. Pull Angle | | Retrieval Time [ 10 sec |
|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD | % Subjects |
| 1 | 21 ♂, 17 ♀ | 2.8 | 1.6 | 8.5 | 5.8 | -22° | 15° | 77% |
| 2 | 17 ♂, 18 ♀ | 4.1 | 1.9 | 15.3 | 10.2 | +9° | 36° | 36% |
| 3 | 18 ♂, 11 ♀ | 2.4 | 1.4 | 7.4 | 4.0 | -30° | 25° | 76% |
| 4 | 13 ♂, 17 ♀ | 3.4 | 1.5 | 13.3 | 11.0 | -23° | 20° | 48% |

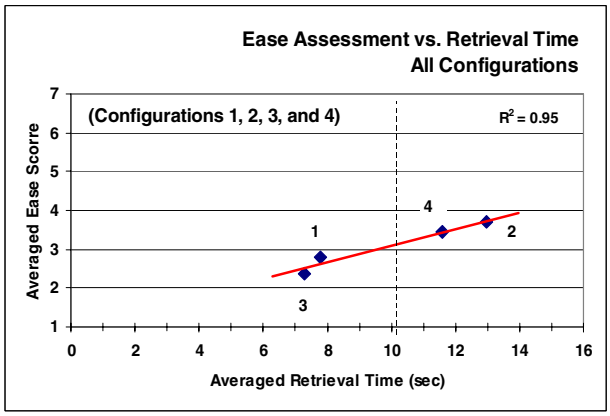


**Figure 23** Ease Assessment vs. Retrieval Time

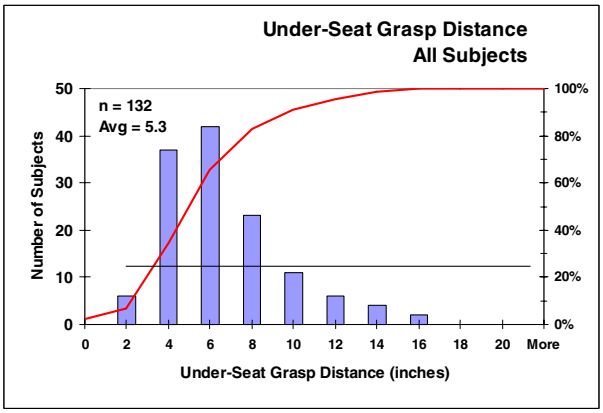


**Figure 24** Under-Seat Grasp Distance Distribution

from the front of the seat frame to the tip of the subject's extended fingers when the subject was directed to reach beneath the seat pan as far as possible. The two-inch difference between reach and grasp distance was estimated from measurements of five subjects. The statistical distribution of the under-seat grasp distance for the subjects is shown in Figure 24. Analysis of these data indicates that approximately 25% of the test subjects had a maximum under-seat grasp distance of 3 inches or less.

The under-seat grasp distance was supported by the results of the tests. In Configuration 4, which failed the EASY10 criteria, the difficulty to extract the stowed life preserver package for many test subjects can be attributed to the aft location of the container. A number of test subjects were able to unsnap the release strap, but were unable to grasp and extract the stowed life preserver package. The release strap locations for the two configurations that passed the EASY10 criteria (1 and 3) were within 3.5 inches of the front of the seat pan.

**2. Container Strap Snap Release Angle.** In Configuration 2, the snap was located near the top of the front tubular beam of the seat frame. In this location, the initial tendency of subjects to pull the release strap in a horizontal-forward or slightly downward direction resulted in multiple attempts to unsnap the strap (Figure 16). This occurred because a near-horizontal pull placed the snap in shear and prevented release of the snap. Most test subjects were able to unsnap the strap by pulling upward. The effort needed to unsnap the strap was also increased by the weight of the subject's thighs, which caused the seat cushion to bear on the snaps.

In the two configurations (1 and 3) that passed the EASY10 criteria, the release strap snaps were on the underside of the seat frame or on the nylon container beneath the seat pan. This allowed the test subjects to pull in a downward direction, as shown in Figures 13 and 19. Approximately 85% of the subjects in Configuration 1 tests and 75% of the subjects in Configuration 3 tests pulled on the release strap at an angle $\theta$ , $-50° < \theta < -10°$.

**3. Occupant Size Effects**. Based on the EASY10 scores and observations made during the tests, the larger subjects (weight > 250 lbs.) had significantly greater difficulty in retrieving the life preservers than the physically smaller subjects (weight <130 lbs.) In Configurations 1 and 4, where the life preserver container was located under the seat pan, the average score for large subjects was 4.8 (n = 16). The combined average scores for Configurations 1 and 4 for smaller subjects was 1.6 (n = 6). Figures 25 and 26 illustrate the relative ease a smaller occupant has in retrieving the preserver, as compared with a large occupant. Thus, the concern for ease of retrieval should focus primarily on larger size passengers.

## CONCLUSIONS

The four life preserver installation configurations tested in this study can be divided into two types. Type 1 has the release strap stud snap mounted on the rigid seat frame, as in Configurations 2 and 3. Type 2 has the stud snap attached to the flexible fabric container, as in Configurations 1 and 4. Based on the results and analysis, the installation features that provided positive results (e.g., easy retrieval) are summarized in Figure 27.

The key feature of the Type 1 installation is the location of the stud snap on the seat frame. In Configuration 2 tests, the subjects tended to pull the release strap in a forward-horizontal direction when the snap was mounted near the top of the frame. This resulted in a shear force on the snaps, which would not open the snaps. The seat cushion bearing on the snaps also made opening the snaps more difficult.

As shown in Figure 27, the mounting position of the stud snap should be on the forward lower quadrant of the seat frame's tubular beam. The figure also indicates that the release strap and the stowed life preserver package should be within 3 inches of the front of the seat frame.

## COMMENTS

Although this study included only four variations of life preserver configurations, the results should be applicable to a wide variety of current passenger seat life preserver installations. The 30-inch seat pitch used in this study should be considered as a conservative factor. Wider pitch installations would likely present less difficulty in retrieving the life preserver, especially for larger occupants. Premium class seats, which often have life preservers located in center consoles or endbays, must be assessed by different methods than those described for this study.

The intent of this study was *NOT* to define or recommend a method to conduct human subject tests to assess life preserver retrieval. Rather, the purpose was to identify installation features that affect the ease or difficulty of retrieving an under-seat life preserver on a passenger seat. No inference should be made that the conclusions described above define precise limits for the

**Figure 25.** Small Female: 107 lbs. weight, 58 ½ inches stature

**Figure 26.** Large Male: 246 lbs. weight, 72 inches stature

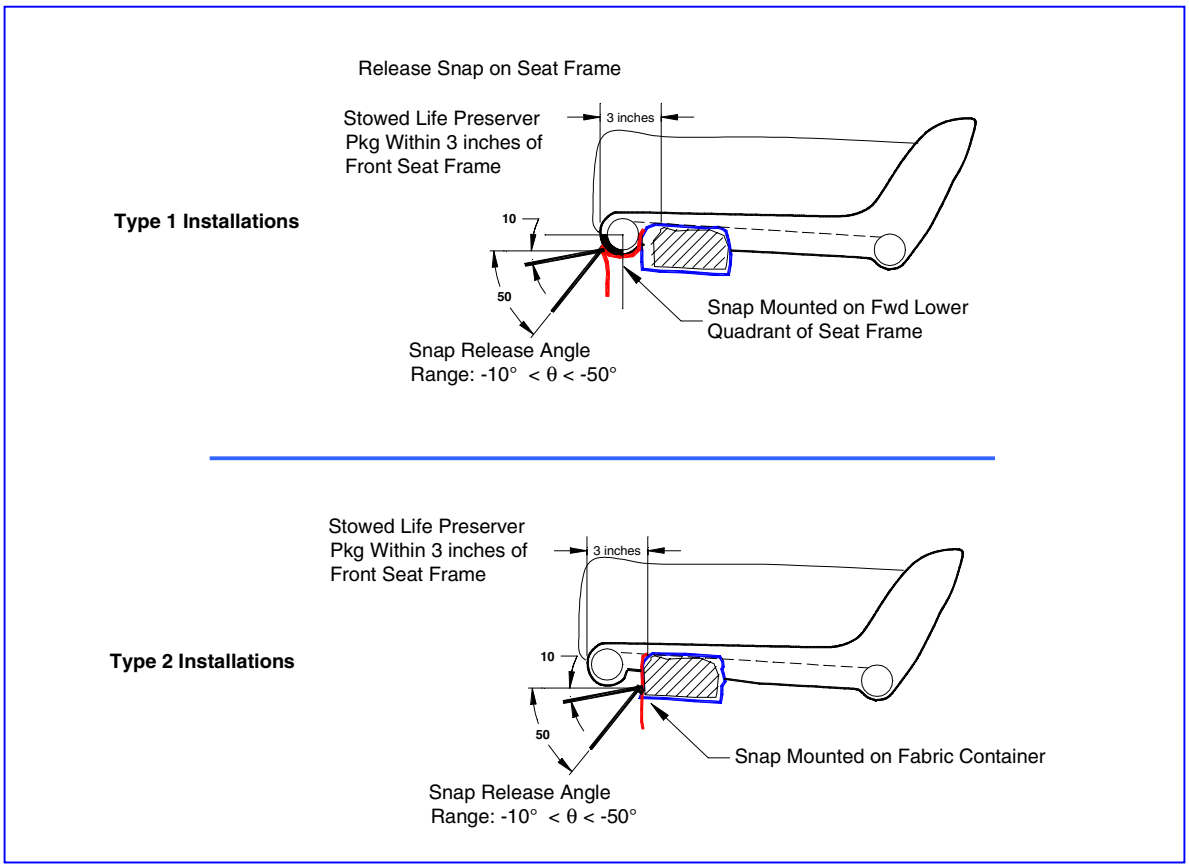


**Figure 27**. Easy Retrieval Installation Features

installation of a life preserver. Rational and reasonable engineering judgement must still be a part of the approval process.

The methods employed in this study involved subjective assessment of the degree of difficulty, since this is the approach used to approve seat installations on transport airplanes. Analysis of the subjective ratings showed a strong consensus among reviewers from varied backgrounds. Anecdotal reports of inconsistent approval decisions during cabin interior inspections of life preserver installations may be due to varied personal opinions on how to assess ease of retrieval. A lack of guidance information or pass-fail criteria may also contribute to inconsistencies in approval decisions.

Data and analysis presented herein provide some general guidance to assist in evaluating the life preserver installation features associated with the "easy reach" requirements in FAA regulations. The installation features described in this report that affected positive (easy reach) outcomes for a wide range of occupant size can be easily verified on most passenger seats. Incorporation of these features by seat designers may also alleviate inconsistency in the installation approval decisions.

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