Federal Aviation Administration

DOT/FAA/20/10
Office of Aerospace Medicine
Washington, DC 20591

Inflatable Emergency Equipment II: Evaluation of Individual Inflatable Aviation Life Preserver Retention Characteristics

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June 2020

Final Report

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/20/10		

4. Title and Subtitle	5. Report Date
Inflatable Emergency Equipment II: Evaluation of Individual Inflatable Aviation Life Preserver Retention Characteristics	June 2020
	6. Performing Organization Code
7. Author(s) Beben, M.S., McLean, C.L., Weed D.B., Ashmore J.D., DeSelms D.E., Guinn K.J., Ruppel D.J., Taylor A.M.	8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aerospace Medical Institute PO Box 25082 Oklahoma City, OK 73125	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., SW. Washington, DC 20591	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplemental Notes

FAA CAMI Aerospace Medical Research Division Project No. 2009-AAM-632-CAB-10066

This study was conducted to measure the retention of aviation inflatable life preservers on wearers jumping into water, as specified by Federal Aviation Administration (FAA) Technical Standard Order (TSO) C13f, Life Preservers, and SAE Aerospace Recommended Practice (ARP) 1354A, Individual Inflatable Life Preservers. Both of these resources establish minimum performance standards and test methods for the development and use of life preservers during transport aircraft emergencies such as ditching. The objective of the study was to provide the Aircraft Certification Service, Systems, and Equipment Standards Branch (AIR-6B0) and the SAE S-9, Cabin Safety Provisions Committee, with recommended revisions to test protocols presented in ARP 1354A and TCO-C13f. This study evaluated seven different models of inflatable life preservers, using wearers who jumped into the water from a height of 5 feet above the surface. Factors studied included the number of inflatable chambers, waist strap adjustment, and arm position while jumping into the water. The study found a significant difference in life preserver retention in regards to inflation chamber type and waist strap adjustment. Arm position did not yield a significant difference in life preserver retention.

17. Key Words	18. Distribution Statement
Life Preserver, Retention, Cabin Safety	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

ACKNOWLEDGMENTS

The research reported in this paper was conducted under the Office of Aerospace Medicine, Protection, and Survival Research Branch, Engineering Sciences Research Section (AAM-632), Cabin Safety Research Team at the FAA Civil Aerospace Medical Institute.

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The authors wish to thank the life preserver manufacturers who provided a new production line and special-order life preservers for the study.

The authors also wish to thank the I-Zone Team at the Civil Aerospace Medical Institute for providing audio, video, and still media coverage of the jumps detailed herein.

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INFLATABLE EMERGENCY EQUIPMENT II: EVALUATION OF INDIVIDUAL INFLATABLE AVIATION LIFE PRESERVER RETENTION CHARACTERISTICS

INTRODUCTION

The Federal Aviation Administration (FAA) is dedicated to enhancing and maintaining the safety of the national airspace system. Regulations and standards are crucial to achieving a uniform level of safety in civil aviation operations. Technical Standard Orders (TSO) are the minimum performance standards issued by the FAA for specific materials, parts, processes, and appliances used on civil aircraft. The FAA updates and evolves these orders as needed. The FAA also works with SAE International to develop Aerospace Standards (AS), which provide technical information in support of the aerospace industry.

TSO-C13 details the minimum performance standards for life preservers used in aircraft. It encompasses materials used on the life preserver; detailed requirements as to their design, construction, and markings; and life preserver testing procedures. Over the years, a few studies have addressed the functionality of life preservers. The National Transportation Safety Board (NTSB) conducted a safety study, *Air Carrier Overwater Emergency Equipment and Procedures,* in 1985, which reported many issues and problems with life preservers. One major issue was the design of adjustable straps. The study indicated that the design could cause a problem in the correct donning of life preservers. The study also reported that creating "universal" sizing caused problems in life preserver design.

A study by Rueschhoff, Higgins, Burr, and Branson (1985) developed a prototype life preserver that addressed several limitations of life preservers. The focus of the study was the development and evaluation of a prototype life preserver. Two aspects of that evaluation looked at the issues of donning and the fit of life preservers. The prototype life preserver differed from the personal flotation device (PFD) that was TSO approved at that time. The prototype was in the style of a jacket with a front zipper closure and a single cell inflator. At that time, TSO-C13d was the standard, and the minimum requirement was for life preservers to have a dual cell inflator (FAA, 1983). The study found that the prototype provided a satisfactory fit for a wide range of adults and achieved an average donning time of 17.5 seconds with a larger percentage of the test group (60%) being able to don the life preserver in less than 15 seconds. One of the most important contributions of this study was that it led to the change of the minimum standard for cell inflator type. The revision of TSO-C13d to TSO-C13e changed the minimum standard from "not less than two separate gastight flotation chambers" to "one or more separate gastight flotation chambers" (FAA, 1986).

On January 15, 2009, US Airways flight 1549, an Airbus A320, made an emergency landing in the Hudson River approximately 8.5 miles from its departure point at LaGuardia Airport. Following its investigation, the NTSB tasked the FAA with reviewing and revising TSO-C13f, Life Preservers, to "ensure that they result in a life vest that passengers can quickly and correctly don" (NTSB, 2010).

The Cabin Safety Research Team (CSRT) of the Civil Aerospace Medical Institute (CAMI) subsequently began its Inflatable Emergency Equipment series of research projects focused on aviation life preservers to support the revision of TSO-C13f. The Inflatable Emergency Equipment project began with an evaluation of aviation life preserver pre-flight briefings, instructional markings, package opening, life preserver donning, and the donning test required by TSO-C13f. That study, *Inflatable Emergency Equipment I: Evaluation of Individual Aviation Life Preserver Donning Tests* (Corbett, Weed, Ruppel, Larcher, & McLean, 2014), found significant areas of concern regarding the usability of aviation life preservers and their associated briefing materials, suggesting that an update to TSO-C13f would be beneficial. As a result of this study, the AS (AS1354 replaced ARP1354A) was revised, and the process to revise TSO-C13f began.

Following the donning study, the CSRT focused on functionality for the next part of the Inflatable Emergency Equipment series. The CSRT had observed that, during water survival activities at CAMI, in the form of Cabin Safety Research Workshops, there was an issue with the retention of life preservers. A video examination of life preserver retention over multiple workshops showed that as many as 29% of life preservers were not fully retained, i.e., they did not remain fully and properly secured on the wearer while jumping into the water.

The FAA certification process for aviation life preservers includes retention (i.e., "jump") tests to evaluate how an inflated life preserver performs its intended function. The retention test method prescribed in FAA TSO-C13f, which was compliant at the time of this study, stipulates that the life preserver must remain attached, undamaged, and not cause injury to the wearer when that wearer jumps into the water from a height of 5 feet above the surface. Importantly, a lack of test method specificity has resulted in a range of retention test conditions, including less challenging tests in which wearers jump into the water holding onto the life preserver and tests in which life preserver movement is less restricted by the wearer. Previous laboratory research (Higgins & Funkhouser, 1986) determined that jump tests in which participants enter the water upright with their arms extended over the head represent the most "severe test of the vest."

TSO-C13f does not specify arm positioning for the life preserver wearer during the jump test, although it does specify that a "means of retaining the life preserver on the wearer, excluding infant-small child wearers, must require that the wearer secure no more than one attachment and make no more than one adjustment for fit" (FAA, 1992). There is no guidance for waist strap adjustment.

Consequently, the FAA's aircraft certification services (AIR) staff are interested in examining the value of various test methods used by original equipment manufacturers (OEM) to demonstrate life preserver retention. The design of this study was formulated to evaluate the different methods used to demonstrate life preserver retention pursuant to TSO-C13f. In consideration, the study examined a range of participant behavior concerning the inflatable life preservers. The aim of the study was to determine best practices to incorporate into future TSO revisions to improve life preserver retention performance.

METHOD

Facilities/Materials

This study utilized the CAMI Water Survival Research Facility (WSRF). The WSRF is a 15-foot-deep water tank with a 4-foot-deep ledge across one end. This project utilized the WSRF ditching cabin simulator, a decommissioned King Air airplane fuselage retrofitted for use in conjunction with the WSRF research tank. The position of the ditching cabin simulator was at the west end of the tank with the top of the "winglet" 5 feet above the water level (Figure 1), as prescribed by the TSO-C13f.

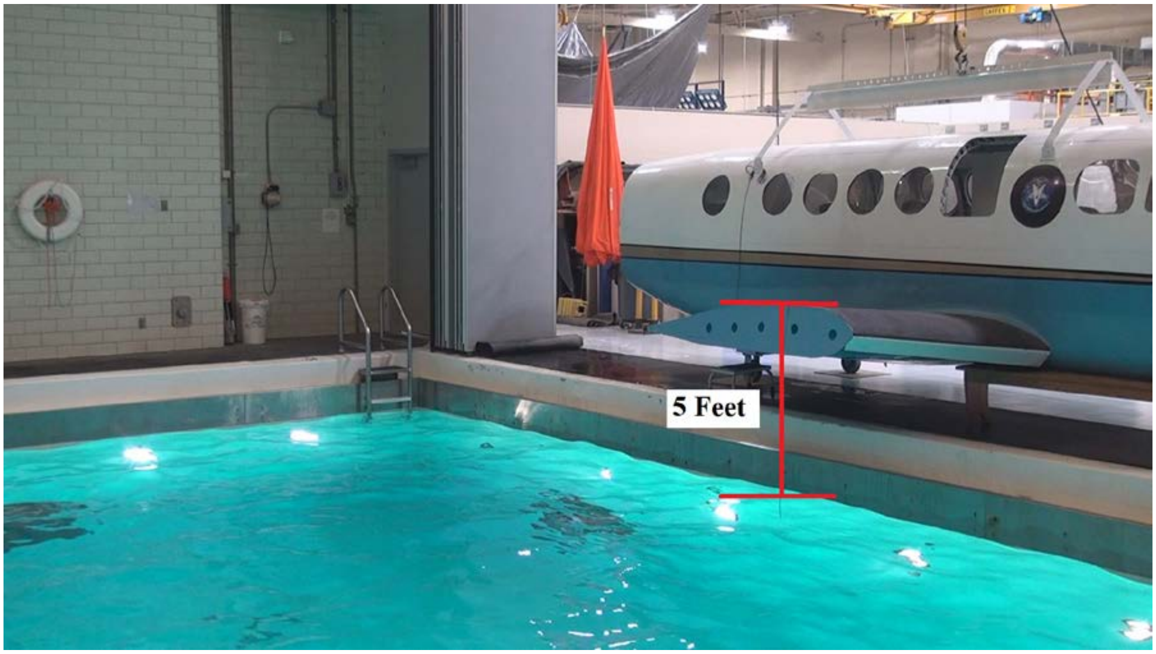

Figure 1: King Air Winglet over the Water Survival Research Facility at CAMI

Data Collection/Reduction. Participants reviewed and signed an informed consent form, per the FAA approved Institutional Review Board Protocol No. 15025 (Appendix A) and filled out a participant information sheet (Appendix B) that included questions regarding demographic information of the participant human subject research volunteers. A high-definition video camera recorded all trials of this study. Delivered recordings were Windows Media Video (.wmv) files. The trials were video-recorded to capture the actions of the individual participants and the retention characteristics of the life preservers they were wearing. Data extraction made use of Windows Media Player and IBM SPSS 23 for statistical analysis.

Life Preservers. Four OEMs provided the life preservers, all new and within their service life cycle. Within the four OEMs, there were seven different models of inflatable life preservers, representative of designs certified for use under TSO-C13f. Table 1 distinguishes each model by OEM and chamber type.

Table 1: Life Preserver Models

OEM	Single Inflatable Chamber	Dual Inflatable Chamber
1	A	D
2	B	E
3	C	F
4		G

All life preservers had a reversible design and oral inflation tubes as well as manual inflation, triggering devices with pull-tabs, and CO_2 cartridges (Figure 2). Three of the models (designated A, B, C) consisted of a single inflatable chamber, one 5.5-inch CO_2 inflation cartridge, and a single oral inflation tube (Figure 3). The other four models (D, E, F, and G) consisted of two 3.5-inch inflatable chambers, two CO_2 inflation cartridges, and two oral inflation tubes (Figure 4). All life preservers (single and dual chamber) used in this study had a single, adjustable nylon web waist strap, attached at the center front of the life preserver, fitted with a single plastic tab at one end to insert into the plastic retaining buckle on the other end.

Figure 2: Single and Dual Chamber CO_2 Cartridges

Figure 3: Single Chamber Life Preserver

Figure 4: Dual Chamber Life Preserver

Life Preserver Neck Characteristics. Each life preserver model had differing neck characteristics. The neck circumference measurement (Figure 5) is the measurement of the round circular hole in the life preserver neck. The neck length measurement (Figure 6) was the extended vertical opening from the bottom of the circle to the stitching. Table 2 details the circumference and neck length of each model used in this study.

Figure 5: Neck Circumference

Figure 6: Neck Length

Table 2: *Neck Circumference and Neck Length*

Model (Chamber Type)	Neck Circumference (Inches)	Neck Length (Inches)
A (single)	15.00	5.75
B (single)	17.25	4.50
C (single)	13.50	5.75
D (dual)	17.00	5.50
E (dual)	15.50	5.00
F (dual)	13.00	5.50
G (dual)	16.50	6.00

Waist Strap Adjustment. Life preservers are equipped with a nylon webbing waist strap fitted with a single plastic tab at one end that inserts into a plastic retaining buckle on the other end. The life preserver is designed so the "wearer secures no more than one attachment and makes no more than one adjustment for fit" (FAA, 1992). This study looked at both a loose adjustment of the waist strap of approximately 2 inches, as shown in Figure 7, and a tight adjustment of the waist strap, as shown in Figure 8.

Figure 7: Loose Adjustment

Figure 8: Tight Adjustment

Arm Position. TSO-C13f does not describe how to position the arms during a jump while wearing a life preserver. This study looked at two arm positions: arms extended up over the head (Figure 9) and arms straight down the side of the body (Figure 10).

Figure 9: Arms in the "Up" Position

Figure 10: Arms in the "Down" Position

Retention. The retention of the life preserver after each jump received a score of a pass (Figure 11) if the preserver remained inflated, was secured around the neck and did not cause injury to a wearer. It received a score of a fail (Figure 12) if it deflated, popped off the neck, or caused an injury.

Figure 11: Life Preserver Was Retained (Pass)

Figure 12: Life Preserver Was Not Retained (Fail)

Experimental Design

This study evaluated the retention characteristics of seven different models of inflatable life preservers, as wearers jumped into water from a height of five feet above the water. The experiment collected comparison data of "jumps" with varying conditions (attitudes). Attitude differences were life preserver chamber type, waist strap adjustment, and arm position (Table 3).

Table 3: *Experimental Design*

Life Preserver Chamber Type	Arm Position/Waist Strap Adjustment			
	Up		Down	
Single inflatable chamber (A, B, and C)	Loose strap	Tight strap	Loose strap	Tight strap
Dual inflatable chamber (D, E, F, and G)	Loose strap	Tight strap	Loose strap	Tight strap

The overall experiment included five sessions of jump trials. During each session, the participant received a life preserver model from one of the four OEMs, being either a single inflatable chamber or a dual inflatable chamber. The participant used that life preserver for a maximum of four times, with an instruction of a different "attitude" with each jump (Table 4). If there was a failure with the life preserver during one of the four jumps, that life preserver was unusable and was not used for the remaining number of jumps. If the life preserver failed on the first jump of the session, a new life preserver was given to the participant and was used a maximum of four times. If the failure occurred later in the session, the participant sat out for the rest of that session. After each session where an issued life preserver was used four times (or failure occurred), a new life preserver was used for the next session.

Table 4: *Number of Jumps per Life Preserver Model (n = 6 subjects)*

Life Preserver Model (Chamber Type)	Participant/Number of Jumps					
	Participant (1)	Participant (2)	Participant (3)	Participant (4)	Participant (5)	Participant (6)
A (single)	4	4	4	4	4	0
B (single)	4	1	4	4	4	0
C (single)	1	2	4	1	0	1
D (dual)	4	4	4	0	4	4
E (dual)	4	4	4	4	0	0
F (dual)	4	4	0	4	4	8
G (dual)	0	0	0	4	4	8

Participants

The participants for this project were volunteers from the Protection and Survival Research Branch (AAM-630). The participants were not naïve on the subject of aviation life preservers; however, they received instruction on how to don the life preserver and were not given a chance to use their experience. There was a mix in both height and weight of the volunteers, which included a small female (62 inches and average weight) to a 95th percentile male (Harrison & Robinette, 2002). Each participant was required to demonstrate his or her ability to swim before testing. Participants received no compensation for participating in this study.

Of the six participants in this study, five were males (one being significantly above average size, i.e., 95th percentile) and one small female. Ages ranged from 30 to 64 years ($M_{Age} = 44.3, SD_{Age} = 13.0$). Height ranged from 62 to 76 inches ($M_{Height} = 70.1, SD_{Height} = 4.2$). Weight ranged from 125 to 333 pounds ($M_{Weight} = 213.3, SD_{Weight} = 61.9$). Girth ranged from 30 to 55 inches ($M_{Girth} = 40.3, SD_{Girth} = 7.2$). Head circumference ranged from 56.5 to 64 centimeters ($M_{HeadCir} = 59.3, SD_{HeadCir} = 2.5$). Neck circumference ranged from 13.0 to 17.3 inches ($M_{NeckCir} = 15.4, SD_{NeckCir} = 1.6$).

Procedure

Before collecting data, the primary investigator reviewed the informed consent with each participant, and the participant signed and dated the form. The facilitator gathered measurements and demographics from each participant, including gender, age, height, weight, girth, head circumference, and neck circumference. The facilitator advised participants ahead of time that they could wear attire that they preferred (e.g., street clothes, swimwear, or wet suit). Participants first demonstrated their ability to swim by swimming a lap across the research tank and back. After all participants demonstrated their swimming ability, the study began. Each participant received a life preserver and donned the preserver on the side of the research tank. They walked over to the King Air fuselage, where the primary investigator was standing to the side of the wing. One at a time, they stepped up on the wing. Each participant received instructions on how to wear the life preserver. First, they received instructions on how to adjust the belt. An instruction to adjust the belt for a "loose" fit meant they adjusted the belt fit to include a 2-inch gap between the strap and their body. An instruction to adjust the belt for a "tight" fit meant they adjusted the belt to fit close to their body with no gap. The primary investigator approved each belt adjustment before the jump.

The second instruction was regarding the positioning of their arms. An instruction to put their arms in the upright position meant they extended their arms over their head (Figure 9). An instruction to put their arms in the down position meant they put their arms straight down the side of their body (Figure 10). The primary investigator instructed all participants not to hold onto the life preserver while jumping into the water. This step was included to better define the most "severe test for the vest," as initially described by Higgins and Funkhouser (1986).

Participants entered the water, one at a time, in an upright position with the adjustment of the life preserver strap as either (a) "loose" fit (at least a 2-inch gap between the strap and their body) or (b) "tight" fit (no gap) and either (1) arms extended up over their head or (2) arms straight down at their side. Each participant tested at least five life preservers. There were eight total combinations (attitudes) of life preserver chamber type, waist strap adjustment, and arm position.

1. Single chamber, loose strap, arms up
2. Single chamber, tight strap, arms up
3. Single chamber, loose strap, arms down
4. Single chamber, tight strap, arms down
5. Dual chamber, loose strap, arms up
6. Dual chamber, tight strap, arms up
7. Dual chamber, loose strap, arms down
8. Dual chamber, tight strap, arms down

Scoring of the jump was more stringent than the TSO jump test criteria. The criteria used for this research included a more detailed interpretation of the life preserver remaining "attached," which required that the life preserver remained secured around the wearer's neck, rather than just remaining tethered to the wearer. Each jump received a score of a "pass" or "fail." A "pass" signified that the preserver remained inflated, secured around the neck, and did not cause injury to a wearer. A "fail" signified that the preserver deflated, popped off the neck, or caused an injury.

RESULTS

The following results detail aspects of life preserver designs and testing procedures that can affect life preserver retention. Results include life preserver model, inflation chamber type, neck circumference, neck length, waist strap adjustment, and arm position.

Life Preserver Model

Seven different life preserver models from four different OEMs were tested. Three of the models used (A, B, C) were single inflation chamber life preservers. The other four models (D, E, F, and G) were dual inflation chamber life preservers. The results applicable to the life preserver model are shown in Table 5. Model F had the highest pass rate (87.5%). Model D had a similar pass rate (80%). Model B had the lowest pass rate of all seven life preserver models (17.6%), while models A, C, and G all had similar pass rates (31-35%).

Table 5: *Results by Life Preserver Model (Chamber Type)*

Life Preserver Model (Chamber Type)	Total Jumps	Pass		Fail	
	n	*n*	%	*n*	%
A (single)	20	7	35	13	65
B (single)	17	3	17.6	14	82.4
C (single)	9	3	33.3	6	66.7
D (dual)	20	16	80	4	20
E (dual)	16	11	68.75	5	31.25
F (dual)	24	21	87.5	3	12.5
G (dual)	16	5	31.25	11	68.75

Note. Chi-square analysis showed that χ^2 (6, N=122) = 34.5, p =0.01.

Life Preserver Inflation Chamber Type

The results for chamber type (single or dual) used are shown in Table 6. Of the 122 jumps, 46 jumps utilized a single chamber life preserver, and 76 jumps utilized a dual chamber life preserver. Dual inflatable chambers had a higher pass rate of 69.7%, while single chambers had a pass rate of 28.3%.

Table 6: *Results by Chamber Type*

Life Preserver Type	Total	Pass		Fail	
	n	*n*	%	*n*	%
Single inflatable chamber	46	13	28.3%	33	71.7%
Dual inflatable chamber	76	53	69.7%	23	30.3%

Note. Chi-square analysis showed that χ^2 (1, N=122) = 19.9, p =0.01.

Life Preserver Neck Circumference and Neck Length

The results for neck circumference are shown in Table 7. The smallest neck circumference had a higher pass rate of 87.5%, while the largest neck circumference had a pass rate of 17.6%.

Table 7: *Results by Life Preserver Neck Circumference*

Neck Circumference (Inches)	Total	Pass		Fail	
	n	*n*	%	*n*	%
13.00 (dual)	24	21	87.5	3	12.5
13.50 (single)	9	3	33.3	6	66.7
15.00 (single)	20	7	35	13	65
15.50 (dual)	16	11	68.75	5	31.25
16.50 (dual)	16	5	31.25	11	68.75
17.00 (dual)	20	16	80	4	20
17.25 (single)	17	3	17.6	14	82.4

Note. Chi-square analysis showed that χ^2 (1, *N*=122) = 34.5, *p* =0.01.

The results for neck length are shown in Table 8. The two preserver models with a neck length of 5.50 inches (80% and 87.5%) had the highest pass rates, while the smallest neck length of 4.50 inches had a pass rate of 17.6%.

Table 8: *Results by Life Preserver Neck Length*

Neck Length (Inches)	Total	Pass		Fail	
	n	*n*	%	*n*	%
4.50 (single)	17	3	17.6	14	82.4
5.00 (dual)	16	11	68.75	5	31.25
5.50 (dual)	20	16	80	4	20
5.50 (dual)	24	21	87.5	3	12.5
5.75 (single)	20	7	35	13	65
5.75 (single)	9	3	33.3	6	66.7

6.00 (dual)	16	5	31.25	11	68.75

Note. Chi-square analysis showed that χ^2 (1, *N*=122) = 34.5, *p* =0.01.

Life Preserver Waist Strap Adjustment

The results for waist strap adjustment (loose or tight) are shown in Table 9. Of the 122 jumps, there were 61 jumps where the individual had the instruction to adjust the waist strap "loose" and 61 jumps where the individual had the instruction to adjust the waist strap "tight." A tight waist strap adjustment had a higher pass rate at 63.9%, while a loose waist strap adjustment had a pass rate of 44.3%.

Table 9: *Results by Waist Strap*

Waist Strap	Total	Pass		Fail	
	n	*n*	%	*n*	%
Loose	61	27	44.3	34	55.7
Tight	61	39	63.9	22	36.1

Note. Chi-square analysis showed that χ^2 (1, *N*=122) = 4.8, *p* =0.03.

Participant Arm Position

The results for arm position (up or down) are shown in Table 10. Of the 122 jumps, 63 jumps occurred with jumpers putting their arms "up" over their heads, and 59 jumps occurred with jumpers putting their arms "down" by the side of their bodies. A similar pass rate occurred between the "up" (55.6%) and "down" (52.5%) arm positions.

Table 10: *Results by Arm Position*

Arm Position	Total	Pass		Fail	
	N	*n*	%	*n*	%
Up	63	35	55.6	28	44.4
Down	59	31	52.5	28	47.5

Note. Chi-square analysis showed that, χ^2 (1, *N*=122) = .11, *p* =0.74.

Attitudes—Life Preserver Chamber Type, Arm Position, and Waist Strap Adjustment

The results for attitudes are shown in Table 11. Of the 122 jumps, there were 66 (54.1%) jumps in which the life preserver passed the jump test, and 56 (45.9%) jumps where the life preserver failed the jump test. To gain a better understanding of the data, the development of "attitude" categories addressed the combinations of arm position and waist strap adjustment.

Table 11: *Results by Attitudes*

		Arm Position				
		Up		Down		Overall
Waist Strap Adjustment		Loose strap	Tight strap	Loose strap	Tight strap	
Single Inflatable Chamber	Total (n)	12	13	11	10	46
	Pass (n, %)	2 (16.7%)	6 (46.2%)	0 (0%)	5 (50%)	13 (28.3%)
	Fail (n, %)	10 (83.3%)	7 (53.8%)	11 (100%)	5 (50%)	33 (71.7%)
		Up		Down		Overall
Waist Strap Adjustment		Loose strap	Tight strap	Loose strap	Tight strap	
Dual Inflatable Chamber	Total (n)	19	19	19	19	76
	Pass (n, %)	13 (68.4%)	14 (73.7%)	12 (63.2%)	14 (73.7%)	53 (69.7%)
	Fail (n, %)	6 (31.6%)	5 (26.3%)	7 (36.8%)	5 (26.3%)	23 (30.3%)
		Up		Down		Overall
Waist Strap Adjustment		Loose strap	Tight strap	Loose strap	Tight strap	
Totals	Total (n)	31	32	30	29	122
	Pass (n, %)	15 (48.4%)	20 (62.5%)	12 (40%)	19 (65.5%)	66 (54.1%)
	Fail (n, %)	16 (51.6%)	12 (37.5%)	18 (60%)	10 (34.5%)	56 (45.9%)

Dual inflatable life preserver chambers outperformed single inflatable life preserver chambers. The dual chamber, tight strap had the highest pass rate (73.7%). The rate was the same for either arm position (up or down). Overall, the pass rate of the dual chamber was 69.7%. The single chamber, arms down, loose strap had the lowest pass rate (0%). The single chamber, arms up, loose strap had a pass rate of 16.7%. Overall, the single chamber preserver had a pass rate of 28.3%. The overall pass rate for the life preservers tested (single or dual) was 54.1%.

Failures

There was a high number of failures when using the criteria set forth by this research project: 56 out of 122 failed (54.1% success). The jump was considered a failure if the life preserver did not remain secured around the wearer's neck. However, if this study had used the criteria set forth by TSO-C13f, only seven life preservers would have failed the jump test (94.3% success). All but seven life preservers remained physically tethered to the participants via the waist strap, although the final location of the waist strap on the participant varied by participant size and waist strap tightness. They remained inflated, secured (by the waist strap in many instances), and did not cause injury to the wearer.

In six out of the seven failures, the life preserver failed structurally during entry into the water. Three of those failures, all model C (Figure 13), failed on the first jump test in the series, with the life preserver tearing at the neckline, deflating the life preserver. Two of the model C failures occurred with the strap in the loose condition, one participant with arms up and the other participant with arms down. The third model C failure occurred with the strap in the tight configuration and the participant with arms up.

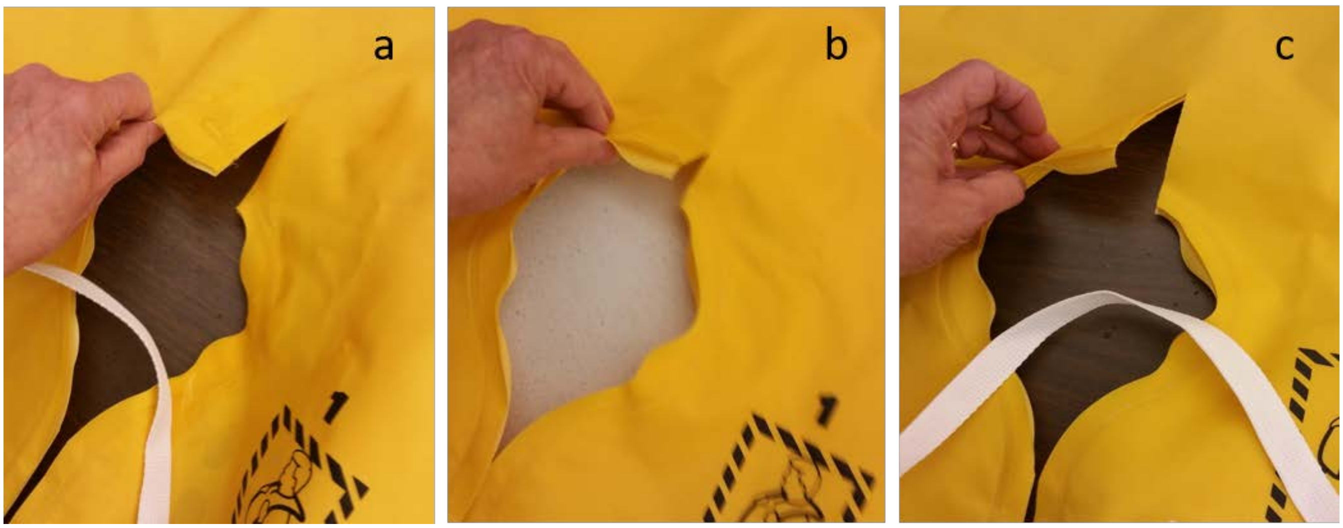

Figure 13: Model C Life Preserver Failures

The other three structural failures involved the waist strap breaking or becoming unstitched. Two of these failures occurred with the model C life preserver (Figure 14a, 14b), one during the second jump into the water with the strap tight, arms up, and the other during the fourth jump into the water with the strap loose, and arms down. The third failure occurred in a model B preserver (Figure 14c) on the first jump into the water, with the strap tight, arms up. Neither strap tightness nor arm position was a significant factor related to failure on entry into the water.

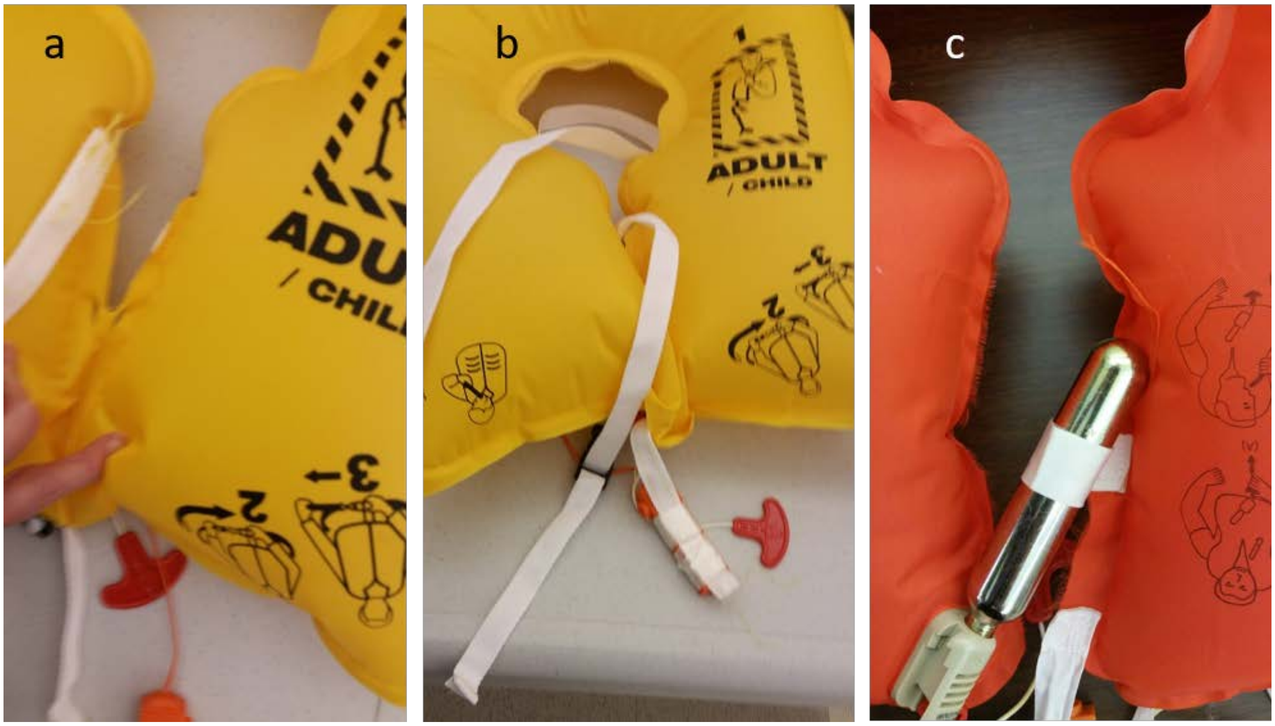

Figure 14: Model C and Model B Life Preserver Failures

The seventh failure caused injury to the wearer of the life preserver with the CO_2 cartridge facing out. Upon entering the water, the life preserver popped off the participant's head, and the CO_2 cartridge hit the participant in the face. This resulted in a score of a failure to this jump because it caused injury outside of the allowable chaffing described in TSO-C13. Thereafter, participants received the instruction to don the life preserver with the canister on the inside.

DISCUSSION

This study looked at multiple factors involving the retention of aviation life preservers on wearers jumping into the water, as might be expected of transport airplane passengers in a ditching scenario. Overall, dual chamber life preservers performed better than single chamber life preservers; the dual chamber pass rate was 69.7%, while the single chamber life preserver retention pass rate was 28.3%. This suggests that having an extra inflation chamber may provide additional security in an actual emergency.

There was a notable difference in life preserver neck circumference and neck length. The smallest neck circumference performed better than larger neck circumferences, and the neck length of 5.50 inches yielded the best results. However, the life preservers that performed better for neck circumference and neck length were also dual chamber life preservers that performed better overall.

Another important factor for retention was a tight waist strap, which kept the life preserver in its place around the wearer's waist. A tight waist strap adjustment performed better than a loose waist strap adjustment. The three failures in which the strap did not maintain a connection between the life preserver and the wearer nevertheless allowed the preserver to be usable as a flotation device. The life preserver did not remain attached to the wearer. However, the wearer was able to grab on to the life preserver and use it as a flotation device. In this situation, however, a life preserver would not be able to right an unconscious wearer such that the mouth and nose of the wearer would be above the surface of the water, with the trunk of the body inclined backward from a vertical position at an angle of 30 degrees, as required by the TSO.

Interestingly, arm position was not a significant factor for life preserver retention. As previously noted, the arms up position was theorized to be a severe test for the retention of life preservers (Higgins & Funkhouser, 1986), but our results did not confirm this assertion. Perhaps because there was an interaction between the life preserver and the positioning of the arms in an upward position, which seemed to create a tighter connection between the shoulders and neck. Specific arm positioning is not a requirement in the TSO-C13f testing of life preservers; perhaps the inclusion of more stringent or detailed requirements would yield better methods for life preserver retention.

Lastly, the combination of the dual chamber and tight strap (arms up or down) performed the best. The combination of the single chamber, arms down, and a loose strap performed the worst. Overall, the dual chamber outperformed the single chamber in all combinations of attitudes.

In the days after data collection, the participants in the study reported several minor injuries. All six participants reported chaffing around the neck, which TSO-C13f specifically mentions as allowable during jump testing. Additionally, one participant reported a painful interaction with a single chamber life preserver CO_2 cartridge, which hit the participant in the face during a jump. The life preserver was donned with the CO_2 cartridge facing outward. When the life preserver detached from around the wearer's neck, the large cartridge hit the participant's chin. No other significant injuries occurred during this project.

Since the completion of this study, there have been significant revisions to both the TSO and the AS. TSO-C13g became effective in February 2017. The revision added a new appendix with required scripts for donning test briefings. The new language includes the verbiage "insert the clip into the buckle and pull the end of the waist strap to tighten the belt" (TSO, 2017). This language gives a more detailed description of the waist strap adjustment, which was not present in TSO-13f. In 2016, AS1354 replaced Aerospace Recommended Practice ARP1354A. The procedure for donning a life preserver was updated to: "Timing starts on signal when the test subject has both hands on the life preserver (i.e., removed from the package) and stops when the life preserver is properly donned, secured, and adjusted for fit (the means of adjustment shall be adjusted for a snug fit on the test subject)." It also states that the retention test requires that "the wearer secure no more than one attachment and make only one adjustment for fit" and it requires that the preserver must remain "inflated, secured, and not cause injury to a wearer" (SAE, 2016).

RECOMMENDATIONS

This study found multiple aspects of life preserver retention characteristics that further research could address. This study focused on the retention characteristics of life preservers by observing the performance of the equipment itself. The study also investigated the interaction between the participant and the life preserver. Future research could enhance this goal with the inclusion of a larger sample size, which might further investigate the physical attributes of participants and the effect on retention. This study should also include a focus on the characteristic of one-size-fits-all for adult and adult-child life preservers.

One finding of note that also bears further investigation is the question of whether life preservers are genuinely reversible. The TSO requirement states that the life preserver "must perform its intended function when reversed" (FAA, 1992). During this study, there was an observation that single chamber life preservers could cause injury if the large CO_2 cartridge was facing outwards. Observation showed that if the life preserver became unattached from the wearer, the cartridge became a hazard to the wearer. This issue warrants further investigation as the general interest from industry, perhaps to save weight, is to adopt single chamber life preservers on transport category aircraft. Such further investigation into assessing the reversibility of single chamber life preservers and their comparable level of safety with dual chamber life preservers, both in regards to performance and the safety of the articles themselves, would be of significant benefit to the safety of the flying public.

CONCLUSION

This study demonstrated that the number of life preserver inflation chambers (one or two) was the primary determinant of life preserver retention, as dual chamber life preservers performed better than single chamber life preservers. Waist strap adjustment, i.e., tight vs. loose (2 inches), was also a factor. Arm position did not yield a significant difference in life preserver retention.

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APPENDIX A – INFORMED CONENT

CIVIL AEROSPACE MEDICAL INSTITUTE
Individual's Consent to Voluntarily Participate in a Research Project

I, _________________________________, understand that this research project entitled *Inflatable Emergency Equipment: Evaluation of Individual Inflatable Life Preserver Retention* is being sponsored by the Federal Aviation Administration and is being directed by Cynthia L. McLean, MA, of the Civil Aerospace Medical Institute (CAMI), Oklahoma City, OK.

PURPOSE: I understand that this project is designed to evaluate certification procedures of aviation life preservers.

CONFIDENTIALITY ASSURED: I understand that all records of this study will be kept confidential, and that I will not be identified by name in any reports or publications about this study, except where photographs may include my picture.

DESCRIPTION OF STUDY PROCEDURE: I understand that I will privately record demographic information (gender, age, height, weight, waist, head measurement) and provide life preserver experience information before the study trials begin. I will receive instructions to don a life preserver and jump into the water survival research tank. My actions will be video-recorded.

DISCOMFORT AND RISKS: I understand that the probability of harm or discomfort anticipated in this research is not greater than that encountered in typical supervised water and swim activities. I will not be exposed to stressful situations and the risk of injury as a result of participating in this study is extremely remote.

PARTICIPANT RESPONSIBILITIES: I agree to allow still photographs and/or videos to be made of me as required during the research, with the understanding that these records are the property of the U.S. Government, and that I am not entitled to monetary or other benefits, now or in the future, for the use of this material. I understand that I will not be identified by name in any pictures or videos of me that are used. I understand that it is important to follow instructions, perform the tasks to the best of my ability, and to be accurate and honest with my responses to demographic and test questions.

BENEFITS: The major benefit to the flying public and me will be improved safety on commercial aircraft.

PARTICIPANT'S ASSURANCES: I understand that my participation in this study is voluntary and that I may withdraw at any point without penalty.

I have read this consent document. I understand its contents, and I freely consent to participate in this study under the conditions described. All my questions have been answered to my satisfaction. I understand that I may contact Cynthia L. McLean at 405-954-7528, should I have additional questions.

____________________________________ ________________
Signature of Participant Date

____________________________________ ________________
Signature of Investigator Date

____________________________________ ________________
Signature of Witness Date

APPENDIX B – PARTICIPANT INFORMATION

Participant Information

Participant No. _____________

A scale and tape measure are provided for your convenience. Please provide the following information.

Gender M F

Age ________________

Head Circumference ________________ cm

Height ________________ inches

Weight ________________ pounds

Waist ________________ inches

Vest Numbers: (a) ______________

(b) ______________

(c) ______________

(d) ______________

(e) ______________