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Inflatable Escape Slide Beam and Girt Strength Tests: Support for Revision of Technical Standard Order (TSO) C-69b

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16. Abstract The ability of inflatable escape slides to provide a safe egress route for evacuees in transport aircraft emergencies depends, to a great degree, on the structural integrity of such slides. Recent certification demonstration evacuations have demonstrated potential problems with the structural integrity of inflatable escape slides; specifically, the strength of the major structural elements of escape slides, i.e., the inflatable beams, has been questioned. With severe loading of the escape slides, the inflatable beams are known to bend, sometimes allowing the sliding surfaces between the beams to form <i>cups</i> that can impede the egress of evacuees by making it hard to climb out of the slide and onto firm footing. This study was intended to develop practical dynamic tests of inflatable beam strength that can be implemented during the developmental manufacturing process for escape slides to identify and correct inadequate inflatable beam strength. The result was the development of a practical test that uses sandbags to simulate human evacuees who are bunched together, <i>toboggan style</i> , during movement down the slide. The test provides data essentially equivalent to that obtained with human test subjects and also provides substantial benefits to human test subject safety. Additional tests of the structural integrity of the escape slide girt (attachment-to-the-aircraft) were also developed to standardize the test procedures for girt strength. Prior manufacturing tests had utilized 2 challenges: static loading of the girt attachment by sandbags laid along the erected slide surface and lateral loading of the girt by a 25-knot wind applied horizontally to the side of the erected escape slide. The new tests use both symmetrical and asymmetrical loading of the girt in a tensile test machine. These tests provide an enhanced ability to assess girt strength, especially as related to ease of execution and replicability of results.					
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Inflatable Escape Slide Beam and Girt Strength Tests: Support for Revision of Technical Standard Order C-69b

INTRODUCTION

Minimum design and performance standards for aircraft inflatable escape slides are defined in Technical Standard Order (TSO) C-69. These criteria have evolved over the years, as new materials and manufacturing methods have been developed. Many of the evolutionary changes have resulted from the need to accommodate ever larger aircraft and passenger loads, and from lessons learned during aircraft evacuations. As the state-of-the-art evolves, advances in inflatable escape slide technology are codified in TSO-C69 to assure that future inflatable escape slide designs are worthy.

Owing to inflatable beam strength problems evidenced by escape slide buckling in a recent full-scale aircraft evacuation certification demonstration, the Performance Standards Working Group (PSWG) of the FAA's Aviation Rule-making Advisory Committee (ARAC) was tasked to develop upgraded inflatable slide beam and slide-to-aircraft attachment means (girt) strength test procedures for use in the development and certification of inflatable escape slides. In response to this charge, the PSWG requested, through the FAA Aircraft Certification Service (AIR3), that a research project be conducted by the FAA Civil Aeromedical Institute (CAMI) to develop new inflatable escape slide beam and girt strength test procedures and success criteria for inclusion in a future revision of TSO C-69.

Discussions aimed toward establishing proper test protocols were held between the PSWG TSO-C69 task team and members of the CAMI Cabin Safety Research Team. Two dynamic beam strength test protocols were initially suggested: 1) an escape slide loading test, in which each lane of the slide is boarded and utilized *toboggan style* by 3 persons weighing a combined total of not less than 510 pounds, followed by additional human *sliders* immedi-

ately boarding and utilizing the slide at 1-per-second intervals for the succeeding 10 seconds, and 2) a sandbag drop test, in which one 250 lb. sandbag per slide lane is dropped to measure potential slide collapse or rupture. The latter test is also designed to determine whether such a concentrated load would cause the sliding surface to impact the ground. For both beam strength tests the escape slides were to be inflated to *pop-off* pressure, as determined by the individual escape slide pressure-relief valve(s).

The success criteria for the toboggan test were based on the ability of the escape slide to regain its original shape after dynamic loading by the human toboggan, so as not to form a *cup* in the sliding surface that would impede the toboggan participants, or subsequent individual sliders, from exiting the slide. The success criteria for the drop test required the escape slide, after bending under the weight of the sandbag, to remain intact, recover its original configuration, and deliver the sandbag to the ground.

The original girt strength tests in the TSO were designed to assure that the attachment point of the slide to the aircraft would support the in-use loads expected. These tests included: 1) a 1050 lb. static loading of the girt, produced by placing sandbags on the escape slide erected to nominal doorsill height, or an angle not greater than 30°, and 2) a lateral loading of the girt, produced by a 25-knot wind directed horizontally, parallel to the ground, against the side of the escape slide longitudinal beam. These tests produced symmetrical and asymmetrical girt loading forces. Two new protocols, designed to replace the original tests, were proposed for the attachment means (girt) strength tests; these also included symmetrical and asymmetrical girt loading forces. In both of the new test protocols, girt specimens were to be mounted in a tensile test machine and pulled according to the type of loading force being considered.

The success criteria required that the girt, and its attachments to the test machine and the inflatable portion of the escape slide, withstand pulls pertinent to the in-use loading forces to which the girts would be exposed. Such loading forces would be determined via instrumentation attached to the girt and/or escape slide during the other usage-rate and loading tests required by the TSO.

BEAM STRENGTH TESTS

Beam strength test options were explored, using both single-lane and dual-lane A330/340 escape slides erected at nominal doorsill heights, in preparation for a larger test series involving an array of inflatable escape slides representative of those in use throughout the transport airplane industry. The goal was to fine-tune the test methodology, and its systematic application by the research team, to provide tests of inflatable escape slide beam and girt strength that were severe, but representative of what escape slides might encounter during an emergency evacuation. Accordingly, both the beam strength tests and their respective success criteria were modified during the test development program. Testing of the additional slides was intended to address the range of slide designs currently in use aboard transport category aircraft, thereby allowing broader generalization of the findings to current, as well as newly proposed, inflatable escape slide designs.

Preliminary Dynamic Loading Tests

The initial dynamic loading tests were conducted on an A330/340 single-lane slide and a dual-lane slide/raft, both inflated to pop-off pressure, using U.S. Air Force personnel attending an aircraft evacuation training class at CAMI. These trainees were physically fit adult males and females in their 20s and 30s. The tests were designed to evaluate only the proper configuration of the human toboggan, which was formed by seating the trainees closely

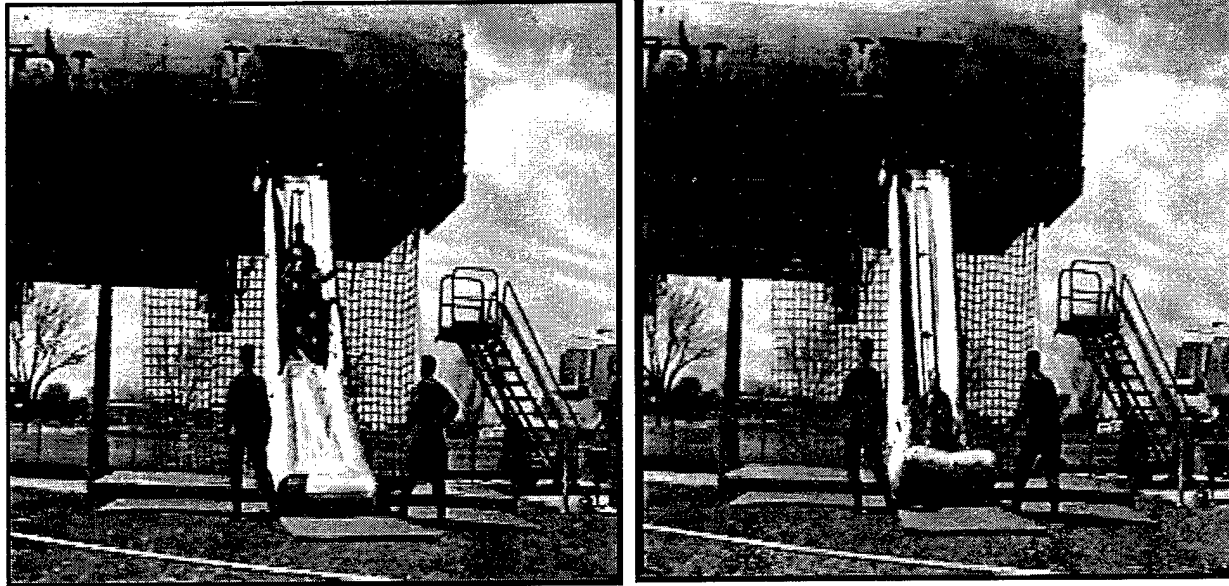
together, single-file at the doorsill, in the center of the sliding lane(s). At the go command, they pushed off in unison, moving as a unit down the slide (Fig. 1).

Depending on the specific trial, either 2 or 3 persons were employed to form the toboggan. Different combinations of trainees were used to achieve toboggan weights ranging from 350 to 580 pounds; this provided assessments of the toboggan weight that would be most appropriate. It quickly became apparent that the original 510 pounds per sliding lane was essentially optimum; however, it was also discovered that almost all of the toboggans produced nearly vertical slide angles during the test. This deformation of the escape slide was so severe at the heavier toboggan weights that questions immediately arose about the likelihood of injury to the 10 subsequent *sliders* who were supposed to follow the toboggan down the slide during the test.

Discussions among the team members about this likelihood of injury resulted in an agreement to develop a sandbag toboggan test that would simulate the human toboggan test and achieve comparable results. Development of this sandbag toboggan test centered on the number, weight, and configuration of the sandbags, as well as elaboration of a sandbag delivery system. All other factors remained the same.

The new tests were conducted with toboggans made of 2 or 3 sandbags, each weighing 150, 200, or 250 pounds, tied together by 1-foot ropes. The toboggans weighed between 400 and 600 pounds. In addition, a fourth bag weighing 200 pounds was also employed in some tests. It was tied with either a 1-foot rope to form a 4-bag toboggan or tethered with a 3-foot rope to the last bag in the toboggan as a *trailer*, to simulate a person jumping onto the slide 1 second after the toboggan was launched. The tests started with the bags being placed at the top of the slide at the doorsill; they were then pushed as gently as possible out of the door and allowed to be gravity-fed down the slide.

Figure 1
Human Subjects Toboggan



The results of this exercise indicated that the sandbag toboggan functioned essentially like the human toboggan. The deformations of the slide appeared essentially identical to those produced by the trainees in the first series of tests, including increased difficulty in exiting the slide at the higher toboggan weights. This effect was caused by more severe cupping of the sliding surface near the bottom of the slide, which effectively raised the toe-end cross beam to a position that could not be easily traversed.

Use of the sandbags with a trailer was plagued with difficulties. Typically, the steep vertical angle produced by the deformation of the slide allowed the trailer to fly past the last bag of the toboggan and land on the ground after minimal contact with the sliding surface. When using both the toboggan with the trailer and the 4-bag toboggan, the bags often piled up together on the slide at the toe end. This occurred not only because of the slide surface cupping described above, but also because the toe-end cross

beam was generally not tall enough, relative to any sandbags already on the ground, for the remaining bags to exit the slide. After much discussion, the use of 3 sandbags with the trailer and/or the 4-sandbag toboggan was deemed inappropriate, given that the success criteria for this test required that all of the sandbags end their descent at the end of the slide on the ground.

Although the replacement of the human toboggan test with the sandbag test, especially without *trailers*, eliminated the ability to assess slide use at a 1-per-second flow rate immediately after severe loading, the sandbag toboggan test, as conceived, allowed robust testing of escape slide beam strength. The ability to adjust the weight of the sandbags provided finer discrimination of the loads that the slide beams could withstand, and the inability of the sandbags to *help* in getting off the slide provided a standardization that could generally not be achieved with human test subjects.

Preliminary Sandbag Drop Tests

The sandbag drop test appeared initially to be fairly well conceived. Again the A330/340 slide and slide/raft inflated to pop-off pressure were tested by sandbags weighing 150, 200, and 250 pounds. The bags were hoisted above the center of the sliding lane and positioned with the bottom of the bags at doorsill height. The bag landing site was chosen by rational analysis to be the location most susceptible (likely to collapse, rupture, or produce contact of the sliding surface with the ground) to a *cannonball* type of jump; the spot was selected for its lack of cross beams, stringer supports, etc., that would strengthen the slide at a particular location. This resulted in the landing site being located along the centerline of the sliding lane surface between the doorsill and a point in the plane of the aircraft floor about 6 feet outside the exit opening (see Figure 2).

Results from the initial sandbag drop tests showed that all 3 bag weights produced significant deformation (buckling) of the single lane slide, although the slides rebounded quickly to transport the sandbags to the ground. The sliding surfaces remained well above the ground. The dual lane slide proved more robust to the challenge of the weights; i.e., there was minimal bending and the bags easily traveled down and off the end of the sliding surface. Given these results, and considering that the initial center of gravity for a person jumping onto the slide would be about 3 feet above the doorsill, the height of the sandbag bottom was increased to 3 feet above doorsill height for the next series of sandbag drop tests.

Positioning the sandbags 3 feet above the doorsill height proved to be much more stringent than necessary. The single lane escape slide buckled severely, and more quickly, reaching essentially vertical angles for all 3 sandbag weights. The rebound was nearly as quick, however, and the sandbags cleared the end of the slides as before. The dual lane slide functioned similarly, reacting more severely than

with the doorsill-height sandbag drops, but it also recovered easily to transport the sandbags to the ground. Neither sliding surface came close to contacting the ground.

Analysis and discussions about the utility of this test, relative to the findings from the original sandbag drop test, led to the conclusion that this form of the sandbag drop test did not offer a measure of slide strength that was representative of a singular maximum anticipated load. A return of the sandbag bottom to doorsill height was considered more appropriate, although the sandbag toboggan tests were beginning to appear better at providing data about recoverability of escape slide shape and function after severe loading. A decision was made to formally compare the 2 procedures early in the next test series.

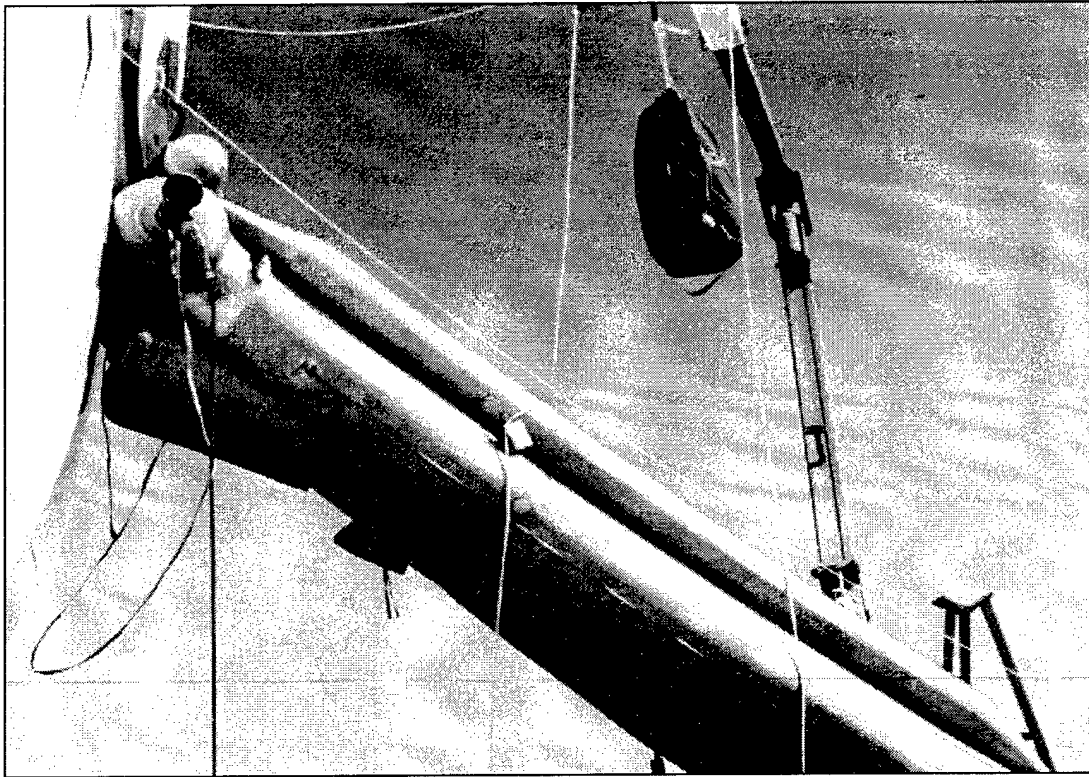
Application To Other Slides

The slides chosen for the tests were representative of a range of inflatable escape slide designs currently in use in the transport category airplane fleet, as well as a prototype under development. Four single lane slides were tested; these included a DC-8, a B-737, an MD-80, and the prototype B-737 slide. One slide each from a B-747, a B-767, and a B-777 aircraft formed the dual lane slide sample. All but one of the sandbag tests were conducted using the CAMI single-aisle Aircraft Cabin Evacuation Facility raised to the nominal doorsill height appropriate for the individual slide being used in the test. The final test was conducted using the B-747 slide attached to its normal Door-5 position on the CAMI B-747 Aircraft Cabin Evacuation Facility.

Sandbag Toboggan Tests

The sandbag toboggan tests were conducted as in the preliminary trials. Based on the findings of the first test series, the weight of the sandbags was set at 170 pounds per bag for the toboggan weights (510 pounds total); a 200 pound trailer

Figure 2
Sandbag Drop Test



was used in a few confirmatory trials. Also, rather than pushing the bags out of the door as before, an adjustable-height, Formica® covered ramp, capable of holding up to 4 sandbags per lane, was positioned inside the aircraft to deliver the bags. This change was intended to reduce the workload of the research team, as well as standardize sandbag delivery. Once loaded with the correct number of bags, the ramp was raised until the bags began to slowly creep, unaided, onto the escape slide. The choice of 3 sandbags per lane, or 3 bags with a trailer, was also varied to allow comparisons with the earlier results. Tables 1 and 2 show the results of the tests.

Sandbag Drop Tests.

The sandbag drop test was conducted on all of the single lane slides, but none of the dual lane

slides. This dichotomy was based on the results from the earlier preliminary tests, where it appeared that the sandbag toboggan test was a more powerful indicator of slide rebound capability, especially for dual lane slides. This approach was substantiated by the results of the subsequent sandbag toboggan tests on the single lane slides, which were shown to bend severely under the heavier 510 lb. load, but recover adequately to allow the sandbags to continue to the ground. The drop test methods were identical to those used in the earlier preliminary tests, i.e., a 250 pound sandbag was dropped onto the center of the sliding lane. The height of the bag was varied, as before, for comparisons with the results obtained in the preliminary trials. Table 3 displays the single lane sandbag drop test conditions and results.

Table 1
Sandbag Toboggan Tests on Single Lane Slides

Aircraft Type	Test	Sill Height	Slide Length	Sliding Angle	Test Condition	Results
DC-8	1	10.5 feet	15.4 feet	43 degrees	Three 170 lb. bags tied 1 ft. apart toboggan style with 4th 200 lb. bag as trailer.	First 3 bags slid together, but 4th bag failed to touch slide and landed on the other 3. All bags bounced off slide.
	2	10.5 feet	15.4 feet	43 degrees	Three 170 LB bags tied 1 ft. apart toboggan style. 4th bag pushed out while toboggan was sliding.	All bags slid well, but 3rd bag was pulled off the sliding surface, landing on the first two. The 4th bag had little effect on the slide and bounced off the end.
B-737	1	8.5 feet	15.5 feet	33 degrees	Three 170 lb. bags tied 1 ft. apart toboggan style.	The bags slid well, as the first 2 pulled the 3rd one out fast. The slide bent slightly.
	2	8.5 feet	15.5 feet	33 degrees	Three 170 lb. bags tied 1 ft. apart toboggan style with 4th 200 lb. bag as trailer.	First 3 bags slid together, but 4th bag landed 7 ft down the slide. All bags slid off the end of the slide.
MD-80	1	8.5 feet	12.5 feet	44 degrees	Three 170 lb. bags tied 1 ft. apart toboggan style	First 2 bags pulled the 3rd bag hard onto the middle of the slide. All bags bounced off the end.
	2	8.5 feet	12.5 feet	44 degrees	Three 170 lb. bags tied 1 ft. apart toboggan style with 4th 200 lb. bag as trailer.	First 3 bags slid together, but 4th bag failed to touch slide and landed on the other 3. All bags bounced off slide.
Prototype B-737	1	8.5 feet	16.75 feet	31 degrees	Three 170 lb. bags tied 1 ft. apart toboggan style.	All bags slid down smoothly, but the slide bent 4 ft. from the end, keeping the bags from sliding off.

Table 2
Sandbag Toboggan Tests on Dual Lane Slides

Aircraft Type	Test	Sill Height	Slide Length	Sliding Angle	Test Condition	Results
B-747	1	16.9 feet	32.3 feet	31 degrees	Three 170 lb. bags per lane tied 1 ft. apart toboggan style with 4th 200 lb. bag as trailer in right lane. (Slide appeared under-inflated)*	All bags traveled straight down the slide, but the trailer didn't touch the slide until 8 ft. from the toe end. The slide cupped and all the bags stayed on the slide.
	2	16.9 feet	32.3 feet	31 degrees	Three 170 LB bags per lane tied 1 ft. apart toboggan style. (Tension straps loose).	All bags traveled straight down the slide, but the slide cupped, preventing the bags from reaching the ground.
B-767	1	14.5 feet	24.5 feet	36 degrees	Three 170 lb. bags per lane tied 1 ft. apart toboggan style.	The bags slid well. Slide bent severely, sprang back, bags bounced onto the ground.
B-777	1	15.6 feet	34.2 feet	27 degrees	Three 170 LB bags per lane tied 1 ft. apart toboggan style. (Slide appeared under-inflated)*	The 3 bags in the left lane slid into the right lane. The slide twisted some, but did not bend. Only 3 of the 6 bags slid off the slide.
	2	15.6 feet	34.2 feet	27 degrees	Three 170 LB bags per lane tied 1 ft. apart toboggan style.	Two bags in the left lane drifted right, but all bags slid off the end.

* Slide was re-inflated for test 2.

Discussion

The goal of this research was to develop tests of transport category aircraft inflatable escape slides that would assure sufficient inflatable beam strength to prevent the sliding surface from cupping and trapping evacuees on the toe end of the slide. The original tests were conceived to assess this capability by: 1) dynamic

Loading of the slide by a *toboggan* of people entering the slide, which would be followed immediately by other persons entering the slide at a 1-per-second flow rate, and 2) the dropping of a large sandbag onto the sliding surface at a point deemed critical for causing collapse, rupture, or contact of the sliding surface with the ground. These 2 approaches were considered to model the most likely assaults that evacuees

Table 3
Single Lane Slide Sandbag Drop Tests

Aircraft Type	Sill Height	Slide Length	Sliding Angle	Test Condition	Results
DC-8	10.5 feet	15.4 feet.	43 degrees	One 250 lb. bag dropped from sill height onto the middle of the slide.	Bag caused severe bending before springing back into shape, bouncing the bag off the end.
B-737	8.5 feet	15.5 feet	33 degrees	One 250 lb. bag dropped from 3 ft. above sill height at 5 ft. down the slide.	Bag slid about 7 feet, bending the slide severely but springing back and bouncing the bag off the end.
MD-80	8.5 feet	12.5 feet	44 degrees	One 250 lb. bag dropped from 3 ft. above sill height at 4 ft. down the slide.	Bag caused less severe bending than was seen with the first two slides and the bag slid off the end of the slide.
Prototype B-737	8.5 feet	16.75 feet	31 degrees	One 250 lb. bag dropped from 3 ft. above sill height at 6 ft. down the slide.	Bag caused intermediate bending compared to the others, this caused the bag to bounce off the end.

would furnish escape slides. Application of the proposed test methods to the problem quickly led to the realization that an alternative method could better provide the answers required, even though the original questions were also somewhat modified by the alternative approach.

For example, in the original toboggan test designed to employ human subjects, early attempts at implementation soon made it clear that the steep sliding angles produced by the human toboggans would imperil those persons comprising both the toboggan and those sliding immediately after. Human injury occurring during the test appeared so likely that the (potential) added safety benefit of assuring that the escape

slide could be cleared by evacuees during times of large static and dynamic loading was offset, if not overwhelmed, by potential injury to test participants. Thus, a change in test methodology was deemed appropriate, even though the ability to witness humans dismounting the slide during the test was forfeited.

The choice of the alternative sandbag toboggan test methodology, albeit without the continuing dynamic component that additional evacuees would provide, appeared to provide the absolute test of beam strength required, and the question of multiple dynamic loading is already being answered by the 70-person-per-minute flow-rate test incorporated in another section of

the TSO. The steep slide angles produced by the sandbag toboggan modeled well the steep angles produced by the human toboggan, and an added benefit provided by the sandbag toboggan test is the ability to answer the same questions about beam strength that the sandbag drop test had been designed to address. This proves to be a very cost-beneficial solution.

The range of effects demonstrated with the sandbag toboggan test also suggests that the test is sensitive to current (state-of-the-art) inflatable slide design and performance characteristics. For example, the slight slide beam under-inflation and attendant softening of the sliding surface employed with 2 of the dual lane slides produced so-called test failures. These effects did not occur for 1 of the escape slides after it was fully inflated; however, the other slide continued to perform poorly when fully inflated, suggesting that it could benefit from additional inflation design pressure or other beam strengthening measures. Thus, the sandbag toboggan test, as currently conceived, effectively addressed both of the original beam strength questions, without the hazards associated with its earlier human-subjects form.

The sandbag drop test also proved to be a forcible test of escape slide beam strength, as almost all of the escape slides bent severely when assaulted by the bag. However, none of the slides displayed any tendency to collapse permanently, or rupture, and the slides were designed with the sliding surface suspended from the top of the lower inflatable beams (as is typical), which prevented any of the sliding surfaces from contacting the ground. The single-lane slides were more sensitive to the drop tests, as they had fewer beams to distribute the load, although there was never a case in which a slide failed to regain its original configuration. The dual-lane slides were more impervious to the drop tests, maintaining their configurations much better. Attempts to make the test brutal enough to produce some sort of failure demanded both weights and drop heights well outside the range of normal operations. This circum-

stance, combined with the ability of the sandbag toboggan to pose essentially the same question, led to the conclusion that the sandbag drop test could be abandoned.

In conclusion, and in response to these findings, proposed revisions to TSO-C69b to address inflatable escape slide beam strength could incorporate the sandbag toboggan test to advantage. Its methodology would include the use of a sandbag(s) toboggan weighing 510 pounds, distributed across an area not to exceed 7.5 feet long by 2 feet wide, delivered by a ramp or other inclined plane located at the top of the slide so as not to propel the toboggan by other than gravity. For multiple lane escape slides, sandbag toboggans should be delivered simultaneously to all sliding lanes. To be successful, all the sandbags comprising the toboggan, if more than one, to reach the ground at the toe end of the slide, except in the case of a multiple sandbag toboggan, where one bag may be resting on top of previously delivered bags and where it would have reached the ground if not for its impediment by the other bags already on the ground.

GIRT STRENGTH TESTS

The original girt strength tests in the TSO were designed to assure that the slide attachment to the aircraft would support the in-use loads expected. One, the 1050 lb static girt loading test, was designed to assure that heavy symmetrical loads could be handled, and the other, a 25-knot wind lateral girt loading test, was designed to assure that asymmetrical loads produced by side-winds did not cause the girt to shear. The 2 new protocols were developed to replace the original tests with more cost- and time- effective methods that employ a tensile test machine to produce analogous symmetrical and asymmetrical girt loading forces.

In both of the new test protocols, girt specimens were mounted in a tensile test machine and stretched according to the type of loading being considered. For each test a girt was attached to 1 end of the test fixture, using the

girt bar attachment typical of installations on the aircraft; the fabric attachment end of the girt was connected to a steel plate drilled to accept the typical girt-to-slide-fabric lacing. The steel plate was anchored to the other end of the test fixture by a mechanical arm positioned to provide symmetrical or asymmetrical tension on the girt. This increasing tension was provided by hydraulic cylinders that forced the girt bar attachment point to move away from the girt-to-slide-fabric lacing joint at a rate of 0.5 inches per second. A load cell placed in the mechanical arm measured the amount of force being applied (see Figures 3 and 4).

The girt loading tests were conducted using worn-out single-lane B-737 girt specimens. The specimens were chosen both for their ready availability and their expected susceptibility to variable tearing loads and locations. The expectation of variability in loading and tearing location was based on the frayed condition that many of the specimens exhibited. Because of the dual girt-to-slide-fabric attachment layers that comprise the B-737 girt, and because all girt specimens were subsequently shown to tear exclusively at the fabric lacing *joint* of each attachment layer, each girt specimen provided 2 test trials.

The results of the girt loading tests proved to be more consistent than originally expected. In the symmetrical loading test trials the initial loading force peaks, indicative of the point at which the girt began to tear, were grouped tightly (see Figure 5). Subsequent force peaks and troughs in Figure 5 show secondary tearing of the girt lacing joint. These test data indicate that the symmetrical girt loading test can provide reliable, reproducible data concerning the ability of girt attachments to withstand loading forces typical of emergency usage. The asymmetrical test data were also generally consistent, although the initial loading force peaks were about half as large as those found in the symmetrical girt loading tests. This resulted from the more concentrated loading, and subsequently easier tearing, of the girts caused by the

asymmetric mechanical-arm-to-steel-plate point of attachment near the outer edge of the girt. The initial loading force peaks were also followed by secondary tearing force peaks and troughs (see Figure 6).

Discussion

Together, these tests provide the qualitative and quantitative findings relative to girt strength that were being sought. The symmetrical loading test provided forces greater than the original 1050 lb static sandbag loading test, and the amount of force applied by the asymmetrical loading test exceeded the 360 lb loading force computed for a girt attached to its B-737 slide being exposed to a 25-knot steady-state lateral wind. These positive test attributes were augmented by an enhanced cost-benefits equation (relative to the original test methods) allowed by the ease of test execution, as well as lesser requirements for personnel and test apparatus.

The application of these mildly dynamic test methods in the current study was intended to challenge the girt specimens until girt failure was achieved. No relevant force requirements had been predetermined as pass/fail criteria. In contrast, application of the test methodology to the design and manufacture of current and future generation girts could use purely static loading forces designed to model the actual in-use and special conditions loads to which specific slide and slide/raft girts would be exposed. Predetermination of the loading forces through instrumentation attached to the girt during other rate and loading tests required by TSO C-69, or mathematical analysis where necessary, would need to be accomplished to establish the pass/fail loading force(s) and the duration(s) of loading force application. These pass/fail criteria should include additional amounts of force beyond those shown to exist for any particular girt, e.g., 150% of demonstrated load, to provide a significant margin of safety for those evacuees who will eventually need to use the slide or slide/raft.

Figure 3
Symmetrical Girt Loading Test Method

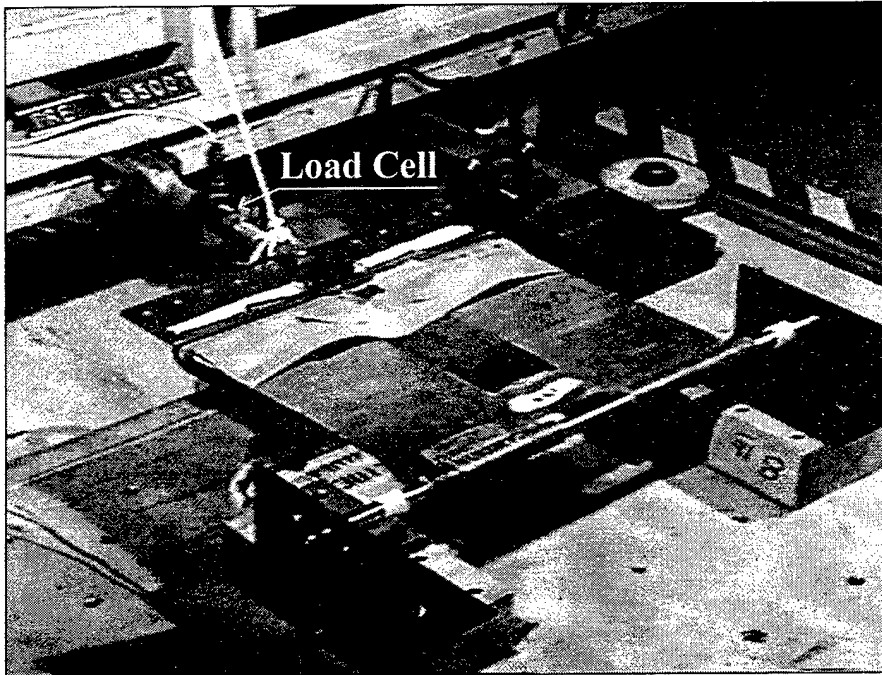


Figure 4
Asymmetrical Girt Loading Test Method

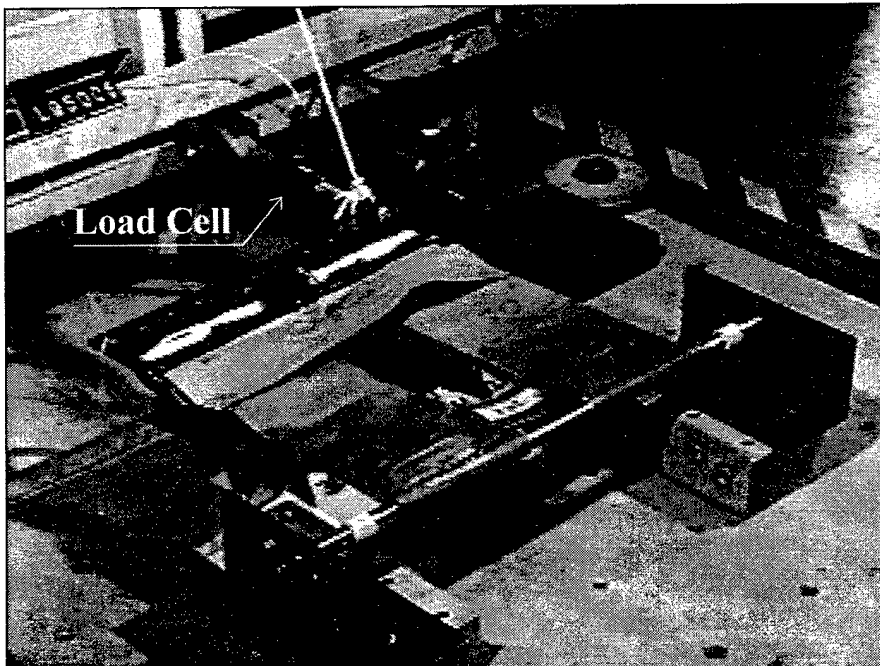


Figure 5
Symmetrical Girt Loading Test Results

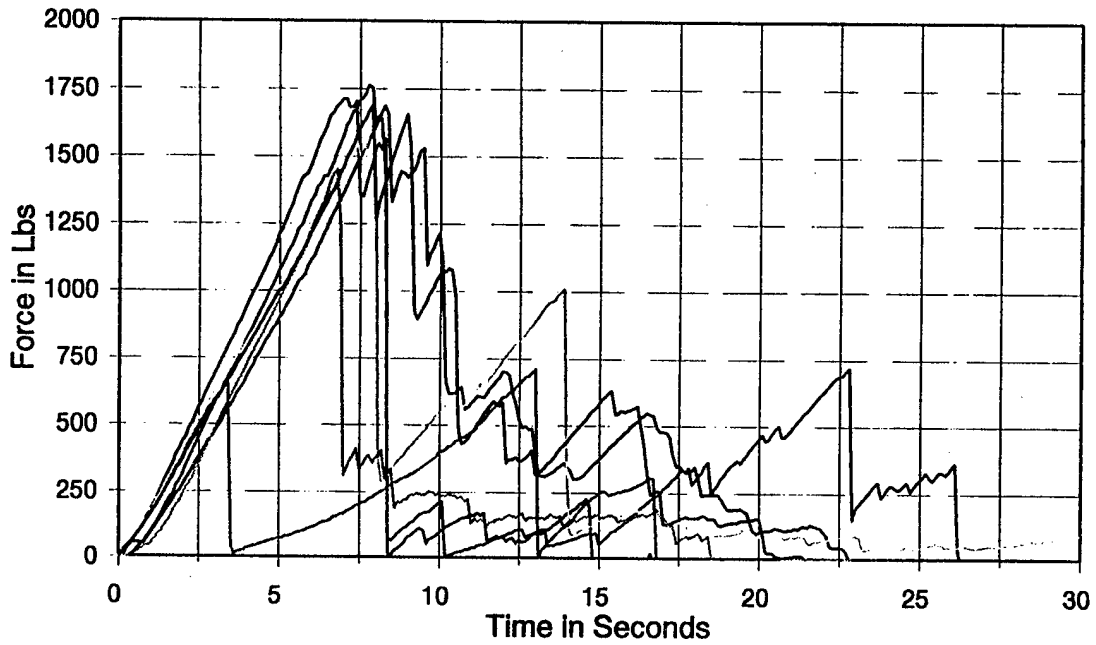
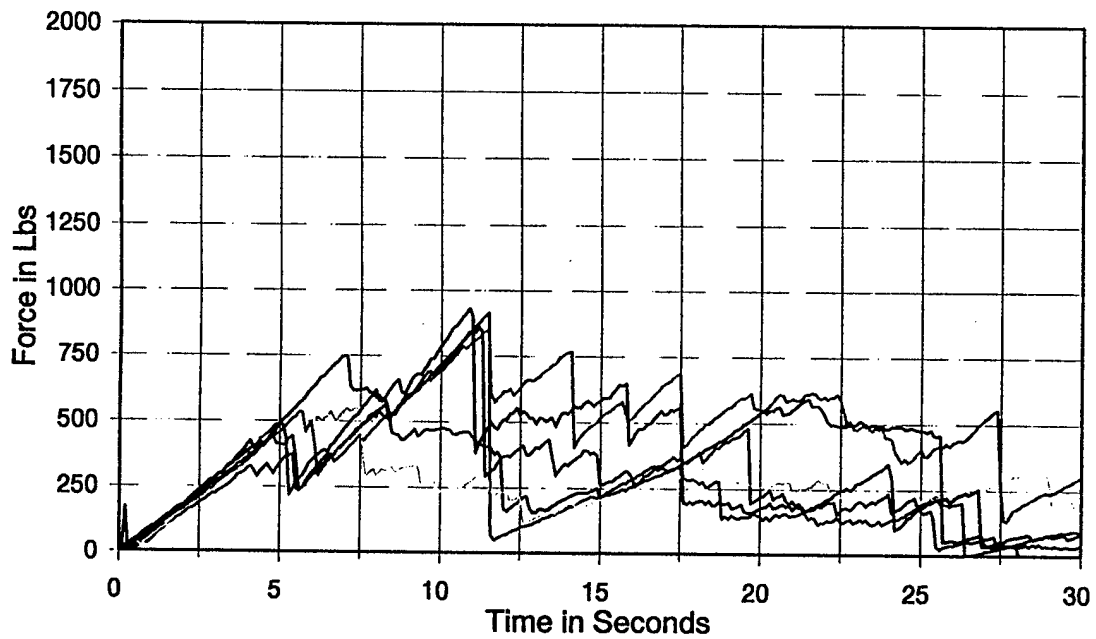


Figure 6
Asymmetrical Girt Loading Test Results



CONCLUSION

Tests of inflatable escape slide beam and girt strength have been developed to assure that current and future inflatable escape slides perform as intended during emergency aircraft evacuations. The beam strength tests resulted from the studied use of human test subjects in comparison with non-human test methodologies designed to mimic slide use by humans. Of particular interest was the ability to properly assess beam strength without the potential for injury of human test subjects. The girt strength tests were designed to imitate loads resulting both from evacuee usage during evacuations and the application of asymmetrical forces created by lateral winds. Also of interest was the ability to create test methods that could be applied in a tensile test machine to improve the reliability of test results, while reducing the need for full scale tests.

The results of the test development program indicate that the resultant beam and girt strength tests provide robust measures of the quality of inflatable escape slides, and that inflatable escape slides manufactured to conform with these requirements should provide aircraft evacuees with a worthy means of emergency egress. Incorporating these tests in any revision of TSO-C69 would be a satisfactory approach to addressing the inflatable escape slide beam and girt strength issues during the manufacturing and certification process.

REFERENCE

Technical Standard Order (TSO) C69b, Emergency Evacuation Slides, Ramps, and Slide/Raft Combinations, Department of Transportation, Federal Aviation Administration, Office of Airworthiness, Washington, D.C., August 18, 1988.