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Volume 1 of 1

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EXECUTIVE SUMMARY

During a routine fire truck systems check on 28 May 2016, a stream of water from a roof-mounted turret on one of the Ottawa International Airport Authority (OIAA) Emergency Rescue Services (ERS) trucks completely displaced eight cabin windows on a B737-200 trainer aircraft. The cabin interior wall panels were also found to be completely displaced and bent out of shape after contact with the seat sets. A subsequent test on the re-installed windows resulted in both window and overwing exit (OWE) door displacement. This unexpected door, window and interior lining displacement pose both a serious safety risk and a potential novel aircraft ventilation and firefighting agent delivery tactic for the Aircraft Rescue and Fire Fighting (ARFF) community.

This report details preliminary tests performed at the OIAA ERS facility which illustrate the potential to quickly, forcefully and remotely displace B737 cabin windows and B-727 OWE doors with a water stream from a fire truck. A preliminary review of other aircraft window and OWE structures is presented as well as ideas for development of a testing and training apparatus for OIAA ARFF personnel, which could be adapted to include a variety of window and OWE structures.

This new information reveals an aircraft design danger with certain window installation methods and exterior OWE door release mechanisms, which could risk injuring passengers who are exiting an aircraft during an emergency. Displaced windows or overwing emergency exit doors could impact passengers and the resulting opening in the fuselage could provide oxygen to an internal fire and an entry point for external fire. The new discovery will also be investigated as a potential novel tool and tactic to assist in fighting aircraft fires.

This preliminary report will be shared with Transport Canada (TC) who will determine if and how the information should be shared with the Canadian and international ARFF communities to increase awareness of the risk and to take appropriate action. In parallel, NRC / OIAA plans to determine the feasibility of using this new information to develop novel ARFF strategies for fighting aircraft fires. NRC / OIAA will seek collaborative opportunities to collect data and advance the test program.

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ABBREVIATIONS

ARFF	Aircraft Rescue and Fire Fighting
B7x7	Boeing 7x7 Aircraft
B7xy	Boeing 7x7 Aircraft – y00 (series) i.e. B732 = B737-200
cm	Centimeter
ERS	Emergency Response Services
ft	Foot
FPS	Frames Per Second
gal	Gallon
gpm	Gallons Per Minute (US)
H	Height
HRET	High-Reach Extendable Turret
kg	Kilogram
lb	Pound
lpm	Litres Per Minute
lps	Litres Per Second
M	Meter
NG	Next Generation
NRC	National Research Council Canada
OIAA	Ottawa International Airport Authority
OWE	Overwing Exit
Qty	Quantity
sec	Second
S##	Fuselage Stringer position
TC	Transport Canada
W	Width

1.0 INTRODUCTION

In November 2015 the Ottawa International Airport Authority (OIAA) Emergency Response Services (ERS) received a B737 as their new ARFF training aid, shown in Figure 1a. The aircraft is equipped with a passenger interior. Prior to this, two freighter B727s had been donated to the OIAA ERS for training purposes, shown in Figure 1b. The freighter aircraft had no cabin windows. Their windows had been replaced by sheet aluminium blanks riveted in place around their perimeters. Thus, it had become common practice during ERS exercises to stream water from the fire trucks anywhere along the fuselage of the B727 training aircraft.

a) B737-200 Passenger ERS trainer

b) B727-200 Freighter ERS trainer with blanked-out cabin windows

Figure 1: Training aircraft of the Ottawa International Airport Authority ERS.

Every morning firefighters conduct a systems operability check on their assigned Aircraft Rescue & Firefighting (ARFF) vehicles, shown in Figure 2 and Figure 3. These checks include, among other things, engaging pumps, flowing water through turrets and hoses and ensuring that the vehicle is defect free and completely operational. Firefighters are using two training aircrafts, B727 & B737 in Figure 1, as targets when they spray water. These training aids are very useful in providing the vehicle operator with a "visual" of the reach of stream efficiency that would otherwise not be possible by simply targeting an empty space such as an open field. Table 1 shows the flow rates for the different apparatus on the fire trucks. The water pressure at the nozzle of a turret or handline is not known.

Panther 6x6	**gallons**	**litres**				
Useable Tankage	3000	11356				
Water delivery	**gpm**	**lpm**	**gal/sec**	**lps**	**lb/sec**	**kg/sec**
Roof Turret						
Primary	600	2271	10	37.85	83.45	37.85
	1200	4542	20	75.7	166.9	75.70
Secondary	375	1420	6.25	23.67	52.16	23.66
	750	2840	12.5	47.33	104.31	47.32
Bumper Turret	300	1135	5	18.93	41.73	18.93
Handline std	125	473	2.08	7.88	17.36	7.87
optional	250	946	4.17	15.79	34.80	15.78
HRET Turret	1000	3785	16.67	63.23	139.11	63.10

Table 1: OIAA ERS ARFF truck water flow rates [1].

During a daily systems check on 28 May 2016, a straight stream of water from a roof-mounted RM60 turret on one of the Rosenbauer Panther 6x6 ARFF trucks completely displaced eight port side cabin windows between the OWE door and main deck cargo door on the B732 ERS trainer. The truck was spraying a straight stream of water as it moved parallel to the fuselage on a track beyond the wing tip. The wing extends 40.52 ft (12.35 m) from the fuselage. This disruption was not discovered by the authors until they entered the aircraft on 24 July 2016. The aluminium interior wall panels were completely displaced and bent out of shape after contact with the seat sets. This unexpected window failure poses both a serious safety risk and a potential novel aircraft ventilation and firefighting agent delivery tactic for the ARFF community.

This report details preliminary tests performed at the OIAA ERS facility, illustrating the potential to quickly and remotely displace B727 cabin windows and overwing exit (OWE) doors with a water stream from a fire truck. This new information reveals an aircraft design danger which could risk injuring passengers who are exiting an aircraft during an emergency. Displaced windows or overwing emergency exit doors could impact passengers and the resulting fuselage opening could provide oxygen to a pre-existing internal fire and/or a potential entry point for external fire. The new discovery will also be investigated as a potential novel tool to assist in fighting aircraft fires.

Figure 2: Rosenbauer Panther 6x6.

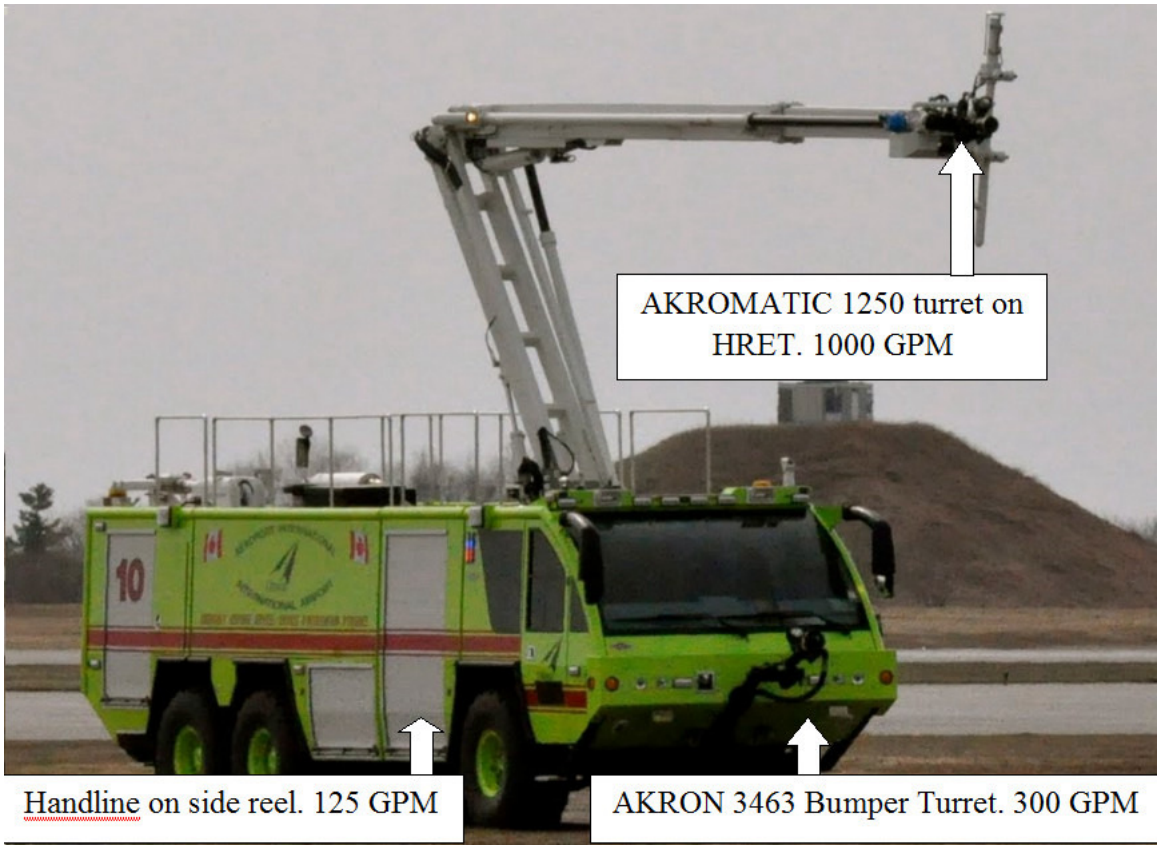


Figure 3: Rosenbauer Panther High-Reach Extendable Turret 6x6.

2.0 CABIN WINDOW CONFIGURATIONS

The information provided in this section is from the author's personal experience, photographs and maintenance manuals. Boeing 727, 737, 747, 757, 767 and 777 aircraft have 10 perimeter clips that locate the two acrylic panes of the cabin window system, shown in Figure 4. Both acrylic panes fit into a rubber gasket. B727 through B767 cabin windows have an exposed surface area of 0.92 ft^2 (0.085 m^2). The B787 has larger cabin windows which require the support of two more clips, one on each side, for a total of 12, shown in Figure 4. Under normal conditions the outer pane in the rubber gasket is forced against the edge of the opening in the forged aluminium frame by cabin pressurization. The second panel in the gasket has a hole in it to allow pressure equalization and aid in relieving condensation. A third transparency (the innermost pane and the one that a passenger can touch) is carried in a fixture on the back side of the cabin liner panel and includes the movable sun shade. The B787 has an electrically dimmable glass inner pane that replaces the mechanical sun shade. The spring-steel clips used by Boeing have changed little over the years as has the method by which they are anchored to the window frame around the perimeter. The contact area on the window assembly and the mechanical restraint imparted by the clips is minimal. The clips serve only to locate the window so that the seal will be in position when cabin pressure is applied. They are easily displaced if force is applied on the window panes from the exterior. This is known to ARFF firefighters as they typically train to displace these windows manually with a maul or axe. This is also known in the de-icing industry as operators have proscriptions against direct spray application on or around fuselage windows or doors as the fluid can be forced past the seals entering the cabin [2]. Fuselage de-icing fluid application is restricted to above the windows and doors and relies on gravity to clear ice and snow from these areas.

a) B737 window with 10 clips. b) B787 window with 12 clips.

Figure 4: Interior view of Boeing cabin windows and clips.

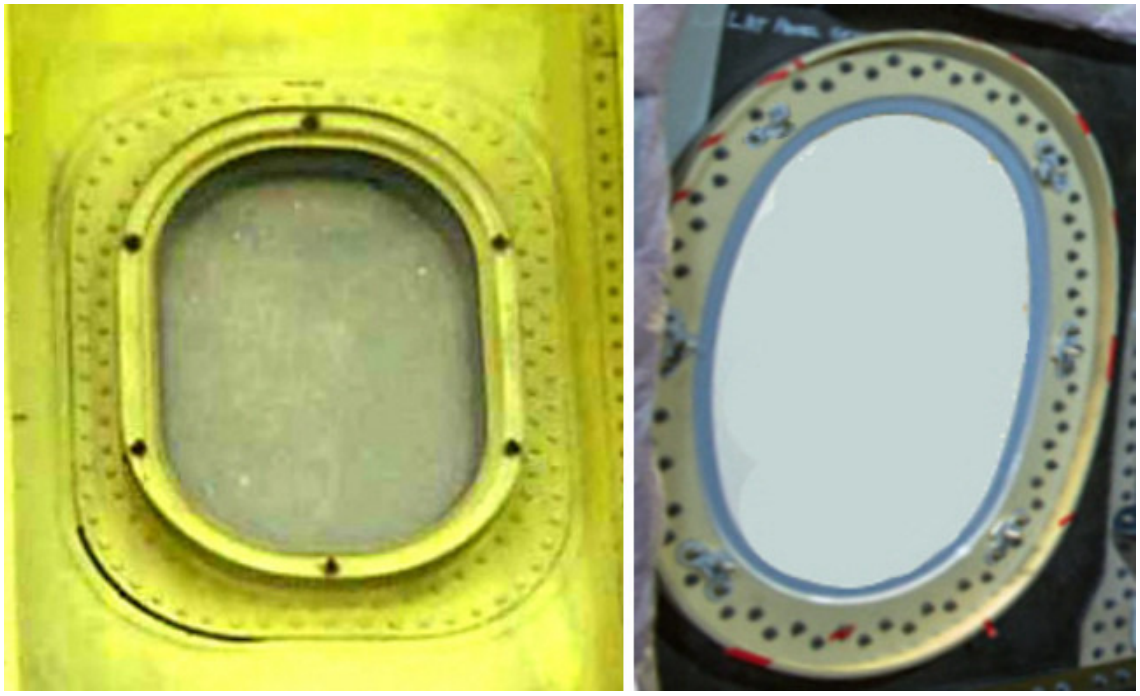
A preliminary survey of other aircraft manufacturers and their cabin window suppliers indicates that the windows of Bombardier commercial jet aircraft excluding the C Series, shown in Figure 5, which are bolted around their perimeter. OIAA ERS personnel have had the opportunity to manually shatter Bombardier Challenger 601 cabin windows, which demonstrated the time it takes to clear the opening, and that sharp edged fragments would remain around the perimeter of the opening, shown in Figure 6.

Figure 5: Bombardier C Series style cabin window assembly.

a) Inner, undamaged b) Outer, fire axe damage c) sharp edge fragments

Figure 6: Bombardier Challenger 601 with 31 bolts (similar to CRJ100/200).

The Airbus family of aircraft follow a different installation methodology where the outer two panes and their pressure seal are retained by a formed metal ring that is secured by six bolts, shown in Figure 7. A330/340 and A380 cabin windows are larger than those on the A320 series. It has not been proven to date whether a water stream could break the fasteners or otherwise displace the panes. It may be that once the panes are shattered manually from the exterior, the pieces can be readily removed by a water stream. The A350 window installation is different, Figure 7b, but it is not know if it is possible to displace these with a water stream.



a) A300 with six bolt retainer ring b) A350 cabin window

Figure 7: Airbus cabin window assemblies.

2.1 CABIN WINDOW TEST RESULTS

After properly re-installing the eight displaced windows, a straight stream of water from the turret of an ARFF truck was directed at the window belt while the truck was parked beyond the wing tip with the water stream nominally perpendicular to the aircraft fuselage. Immediately as the water stream contacted a re-installed window, the window was again displaced into the cabin, shown in location A in Figure 8. The stream was started again and was rotated towards the aft fuselage windows that had not been previously disturbed and presumably remained as they were when the aircraft was operational. This action displaced the over-wing exit (OWE) door and then pushed in one of the aft cabin windows, shown as location B in Figure 8. The photograph in Figure 8 was taken from the front of the cab of the fire truck. This test used the turret on the end of the HRET boom, thus the water stream originated from a closer position to the aircraft. The HRET turret has a maximum flow of 1000 gpm (3785 lpm). Note that only the turret was rotated during the second application making the angle of water impact on the door and aft window progressively extreme (from 90 to approximately 60 degrees relative to the fuselage longitudinal axis).

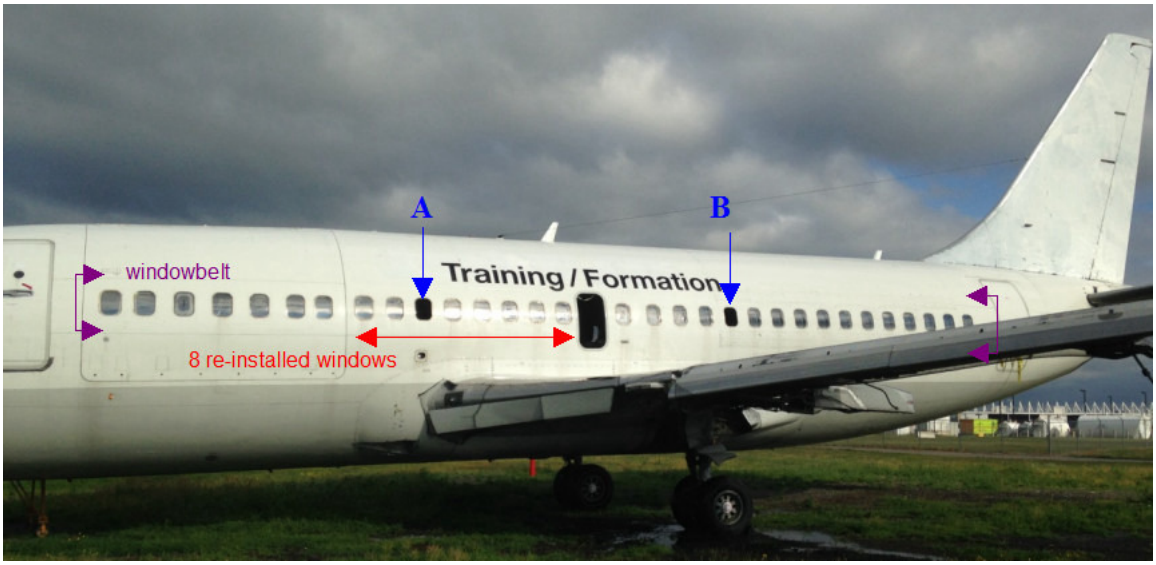


Figure 8: Two cabin windows (at A & B) and OWE door pushed in by water stream.

The windowbelt is the section of the fuselage sidewall that incorporates the cabin windows, shown by arrows in Figure 8, with the inner surface shown in Figure 9. The skin sheet layers are thicker along this belt than in other areas to support all the openings in the fuselage pressure vessel. The multiple sheet layers and window frames make this a more difficult area to breach for firefighting and forced-entry rescue.

Figure 9: B737 windowbelt zone between stringers S10 and S14 right and left.

Figure 10 shows the interior view of the window pane and cabin liner damage and displacement caused by the water stream striking the window at location B. Figure 9 shows the inner surface of a section of B737 fuselage illustrating the bare structure of the windowbelt area.

None of the Ottawa airport ERS firefighters had previously experienced this type of damage to cabin window installations due to unintentional displacement. This may be because their previous training opportunities had not included an aircraft with cabin windows. A message sent

in July 2016 to 74 ARFF officers at airports across Canada confirmed that no one else in the industry had observed or deliberately done this either.

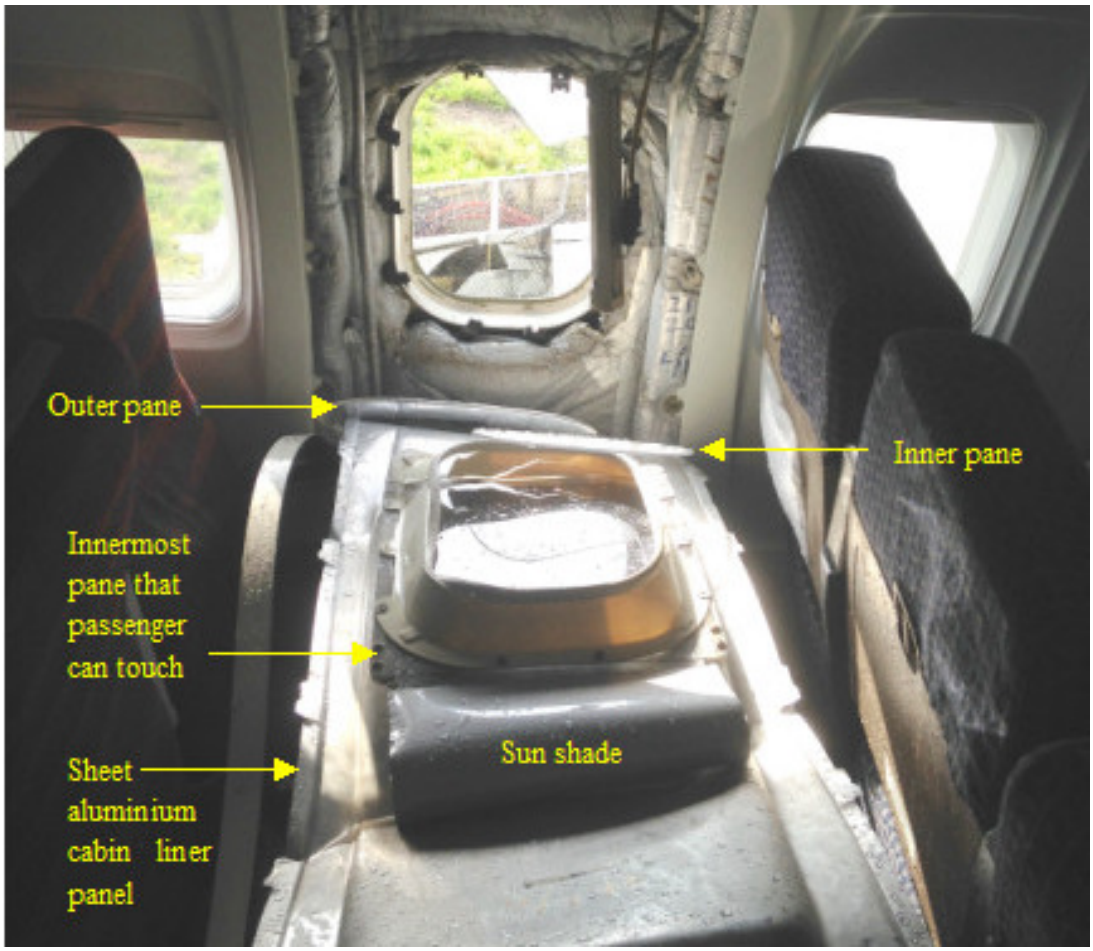


Figure 10: Results of water spray on the window panes and cabin liner panel at location B.

2.2 CABIN WINDOW TEST – INTERIOR VIEW

To better understand what was happening, a test was set up against a single window in the starboard aft area of the B737 cabin and cameras were positioned to record the external and internal views simultaneously, shown in Figure 11.

a) truck & camera b) target window (arrow) c) interior camera (post-test)

Figure 11: B737 Cabin side window test setup.

After the test the outer pane showed impact damage in two locations along the lower edge, having broken into three pieces. The cabin liner was completely displaced, bent and found almost in the centre aisle, as shown in Figure 12.

a) cabin window panes – L, inner: intact, R, outer: broken b) cabin liner

Figure 12: Post-test B737 cabin window damage.

The fire truck driver's position in the cab relative to the turret on the cab roof made it difficult for the operator to target one specific window because the view was obscured by the water stream and spray once it deflected off the fuselage. Three attacks were conducted before the water stream was successfully directed onto the selected window. The camera records show that little water impacted on the window in the first two attempts from 100 and then 65 feet (30.5 and 19.8 m). Using hand signals, the operator was guided onto the window from 45 ft (13.7 m) – basically just beyond the wing tip. In this third attempt the truck pumped water for 12 seconds total, consuming 240 gallons (757 liters). Water was impacting in the area of the windowbelt for 6 seconds. The target window started to vibrate as the water impacted it and it failed within the first second of direct contact. Sequential screen shots from the exterior and interior videos are shown in Figure 13a) and b).

a) before b) flow starts c) on window d) off window e) below window f) after

a) Exterior view

a) before b) window breached c) d) e) f) after

b) Interior view

Figure 13: Cabin side window trial on B732 Passenger ERS training aircraft.

The truck positions for the cabin window and first OWE water penetrations on the B732 are summarized graphically in Figure 14.

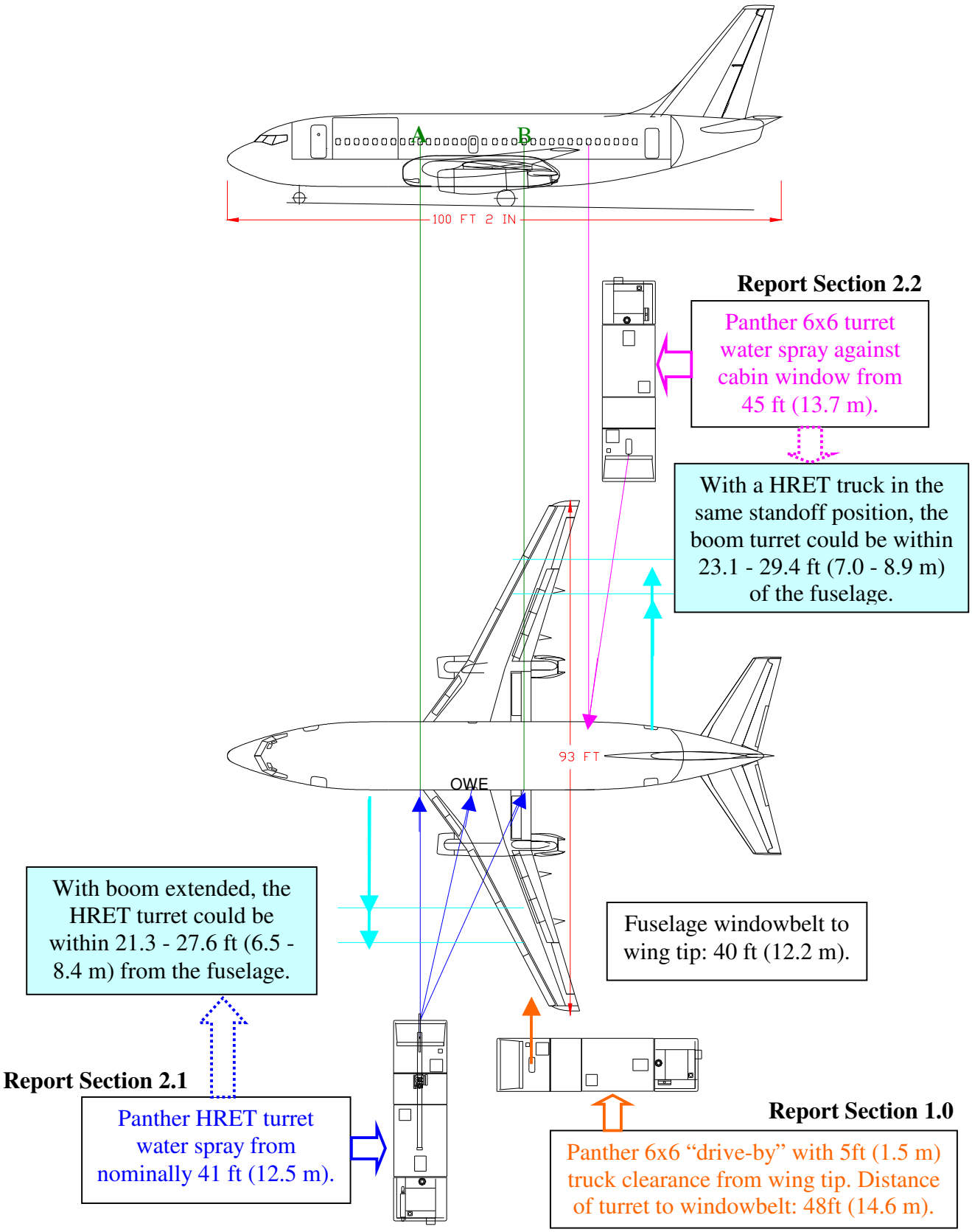


Figure 14: B737 cabin window and OWE water penetration tests.

3.0 EMERGENCY OVERWING EXIT CONFIGURATION

As discussed in Section 2.0, preliminary tests also revealed that a fire truck water stream could also displace OWE doors. The following sections detail two separate tests which capture video both external and internal to the aircraft to document the effect. These tests were conducted on the B722 Freighter aircraft. Only the forward OWE doors are operational.

Two OIAA firefighters have since admitted to unintentionally displacing OWE doors on the B722s in the past. They just thought they had not been installed properly and so they did not report the event or attach significance to it, further highlighting the need for further education.

The manual release panel on the exterior of the aircraft OWE needs only to be big enough for one hand to operate it and so the target for the water stream to contact is relatively small. On an Airbus A320 the manual release panels are nominally 3 inches high by 4 inches wide or 12 square inches (7.6 cm x 10.2 cm or 77.4 cm^2), representing a 0.08 ft^2 (0.008 m^2) target. Boeing 732 OWE release panels are slightly larger, being 3.12 inches high by 5.5 inches wide (7.9 cm x 13.9 cm), and thus present a slightly larger target of 0.12 ft^2 (0.01 m^2). These are small targets to hit accurately from a distance of 50 ft (15.2 m) or more, yet both the roof turret and HRET turret water streams have successfully operated the OWE release panels very quickly after pump start with little to no prior practice of the technique. They have also been hit accidentally.

OWE Type IIIA. This type of OWE is a plug type rectangular opening of not less than 20 inches (51 cm) wide by 36 inches (91.4 cm) high with corner radii not greater than 7 inches (17.8 cm), and with a step-up inside the aircraft of not more than 20 inches (51 cm). If the exit is located over the wing, the step down outside the aircraft may not exceed 27 inches (69 cm). The OWE opens inwards and once released by actuation of the external panel (push inwards) or internal handle (pull downwards) becomes free of the aircraft structure [3].

OWE Type IIIB. This type of OWE has similar dimensions as the Type IIIA but is hinged at the top and rotates outwards and upwards upon release through spring-loaded actuators, and remains attached to the aircraft while held by up-locks in the lift mechanism. To prevent unintended actuation, the exit is secured by a solenoid driven pawl governed by the proximity switch electronics unit. With the solenoid energized, the pawl locks the OWE torque tube from rotating.

For the B737NG [4], the overwing exits lock based on several aircraft system logic rules during takeoff roll and flight:

- Three of the four entry/service doors must be closed and,
- both the left and right thrust levers have been advanced to more than 53 degrees of throttle lever angle and,
- the airplane air/ground logic indicates that the airplane is in the air or both thrust levers have been advanced.

The overwing exits unlock when any of the above conditions are not met, as happens during landing rollout or DC power is lost.

When the 28VDC flight lock relay circuit is de-energised a return spring pulls the pawl clear so that the torque tube can rotate and the OWE door can open.

As shown in Table 2, some Boeing Type IIIA overwing exits require a force of up to 30 pounds (13.61 kg) to activate the door release mechanism. Other Type III OWEs can weigh up to 60 pounds (27.22 kg). As of the end of 2016, over 16,000 currently operating aircraft have OWEs, while a further 6000 are on order. Type IIIB OWEs represent 34% of the aircraft listed in Table 2 and 48% of the aircraft with OWEs on order.

Aircraft	Type III OWE				Opening	2016	Aircraft	On
Model	Qty	H	W	Weight	Force	Census	Model	Order
A318	2	3'4" (1.02 m)	1'10" (0.56 m)	32.5lb (14.7 kg)	6.7 lb (3 kg)	43	A319	6
A319	2 or 4	3'4" (1.02 m)	1'7.7" (0.5m)	32.5lb (14.7 kg)	6.7 lb (3 kg)	1327	A319neo	46
A320	4	3'4" (1.02 m)	1'7.7" (0.5m)	32.5lb (14.7 kg)	6.7 lb (3 kg)	3866	A320	370
A320neo	4	3'4" (1.02 m)	1'7.7" (0.5m)	32.5lb (14.7 kg)	6.7 lb (3 kg)	10	A320neo	2355
B721/722	4	3'2" (0.97 m)	1'8" (0.51 m)	45 lb (21 kg)	15 lb (7 kg)	64		
B732/3/4/5	2 or 4	3'2" (0.97 m)	1'8" (0.51 m)	46 lb (21 kg)	15 lb (7 kg)	858		
B736/7/8/9	2 or 4			Type IIIB opens up	22-33lb (10-15kg)	5567	B737/8/9	798
B752/3	4	3'2" (0.97 m)	1'8" (0.51 m)	50 lb (22.7 kg)	30 lb (14 kg)	55	B737Max	1923
B762/3	2 or 4	3'2" (0.97 m)	1'8" (0.51 m)	60 lb (27 kg)	30 lb (14 kg)	458	B763	77
CRJ 100/200	2	3'0" (0.91 m)	1'8" (0.51 m)	35 lb (16.8 kg)	25 lb (11.36 kg)	560		
Global 7/9/1000	4	3'7" (1.09 m)	1'8" (0.51 m)	42 lb (19 kg)	25 lb (11.36 kg)	751	Global 7/9/1000	50
CS100/300	2	3'6" (1.08m)	1'11" (0.59 m)	Type IIIB opens up	unknown	7	CS100/300	274
ATR 42	2	3'0" (0.91 m)	1'8" (0.51 m)	unknown	Rotate lever	236	ATR 42	12
ATR-72	2	3'0" (0.91 m)	1'8" (0.51 m)	unknown	Rotate lever	706	ATR-72	171
ERJ-145	2	3'0" (0.92m)	1'8" (0.51 m)	unknown	Rotate lever	479	EMB-190/5	56
EMB-190/5	2	3'2.6" (0.98m)	1'8.9" (0.53m)	unknown	Rotate lever	623	EMB 190/5 E2	87
Fokker 70,100	2 or 4	3'0" (0.91 m)	1'8" (0.51 m)	unknown	unknown	154		
MD-83/90/95	4	3'0" (0.914 m)	1'8" (0.51 m)	31 lb (14.1 kg)	unknown	623		
					Total Operating	**16387**	**Ordered**	**6225**

Table 2: OWE size, weight and activation force for Commercial Aircraft [5, 6].

There are aircraft with Type III OWEs that cannot be opened with a water stream because the exterior actuator is a handle that must be raised from a recessed, flush position and then rotated [App A]. For example there are currently 623 active MD-80/90 and B717 (MD-95) series aircraft, and 2044 active ATR 42/72 and Embraer ERJ-145 and EMP 190/5 aircraft with such recessed release handles.

Both B757 and 767 have two-step OWE exterior handles as shown in Boeing documents arff757.pdf, Pg 757.0.2 and arff767.pdf, Pg 767.0.2, dated May 1, 2012 [7]. It is not known at

this time if these variants to the Boeing OWE external release panel can be actuated by a water stream.

Appendix A contains pictures of various TYPE III and IV OWEs and notes on their operation from the manufacturer's ARFF crash chart or aircraft recovery document [8, 9, 10, 11].

In OWE doors that have windows, the windows are constrained by the bezel and door interior liner, such that these window cannot be displaced by a water stream. Opening the OWE itself would be the preferred option to breaking the window panes and clearing the fragments.

The top edge of the exterior release panel on a B732 Type IIIA OWE is nominally 1.12 inches (2.84 cm) from the top edge of the door. If this proximity to the top edge holds true for the Type IIIB door, it may be that a water stream can actuate the panel and allow the door to release and begin to swing up and out. The concern is that a stream of water impacting below the release panel on the door could interfere with the upwards movement.

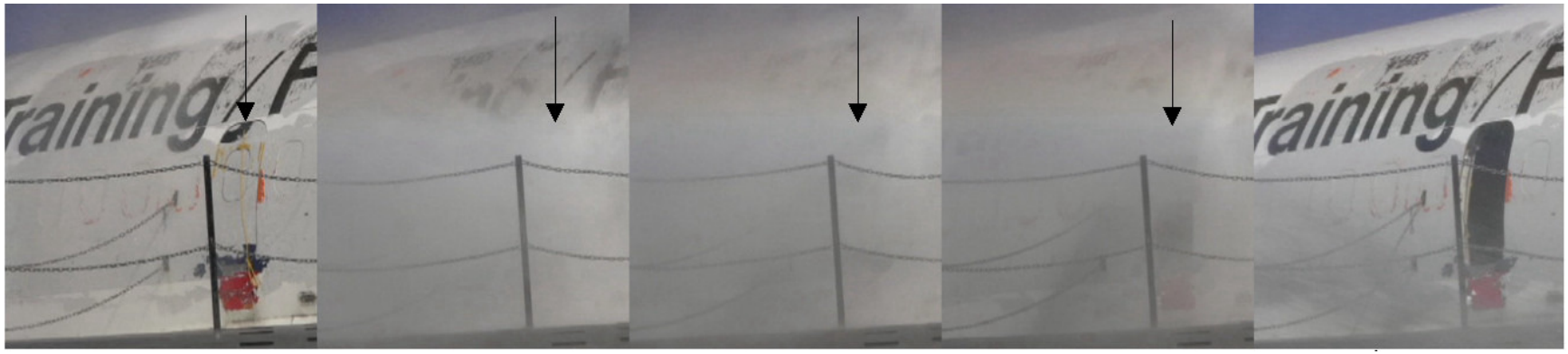
Some of the larger business jets use Type III OWEs as well. The Bombardier Challenger series and Learjet 40/45 have exterior push panels like the Boeing and Airbus commercial jets. The Dassault Falcon family and Hawker Siddley HS.125 plus the Beachcraft Corporation Hawker 750/800/850XP/900XP series all use a push button at the top of the door. Details of these are listed in Table 3 with photographs provided in Appendix A. It is not known at this time if the external push buttons can be actuated with a water stream, as the button is small.

Aircraft Model	OWE	**Exterior release**	**Aircraft Built**
Challenger 600/1/4/5 and 650	1	**Push Panel**	**1000**
Learjet 40/45	1	**Push Panel**	**632**
Falcon 900/EX	1	**Push Button**	**500**
Falcon 10,100, 20, 200, 50	1	**Push Button**	**1086**
Falcon 7X/8X	1	**Push Button**	**264**
Falcon 2000/EX	1	**Push Button**	**310**
HS.125	1	**Push Button**	**901**
Hawker 750/800/850XP/900XP	1	**Push Button**	**650**
MU-300 or Hawker 400/A	1	**unknown**	**951**
Pilatus PC-12	1	**Push Panel**	**1400**
		Total	**7694**

Table 3: Business and commuter class aircraft with Type III OWEs [12].

3.1 B737 OWE DOOR TEST – EXTERNAL VIEW

On 2 August 2015, a fire truck was positioned in front of the port wing just inboard of the B737 wing tip. The roof turret was engaged and a solid water stream (pump delivery rate of 1200 US gpm or 20 gal/sec (4,524.5 lpm or 75.7 lps) was directed at the fuselage nominally 100 inches forward of the forward port over-wing exit, at window height. Water impacted the fuselage side 4.00 seconds after the pump started based on analysis of video and audio recorded (29.97 frames per second (fps)). The stream was rotated aft until the door was reached at 7.83 seconds. With the water spray obscuring the view, confirmation could not be made that the door had displaced until 8.27 in the video. Water delivery continued until 12.40 seconds. Therefore the duration from water first impinging on the door to displacement was nominally 0.44 seconds, while total water used was no more than 200 US gal or 6% of the 3000 US gallon on-board supply (757 l of 11,356 l). Note, the OWE release panel is located at tip of arrow shown in Figure 15.



0 7.83 8.27 8.67 12.40 seconds

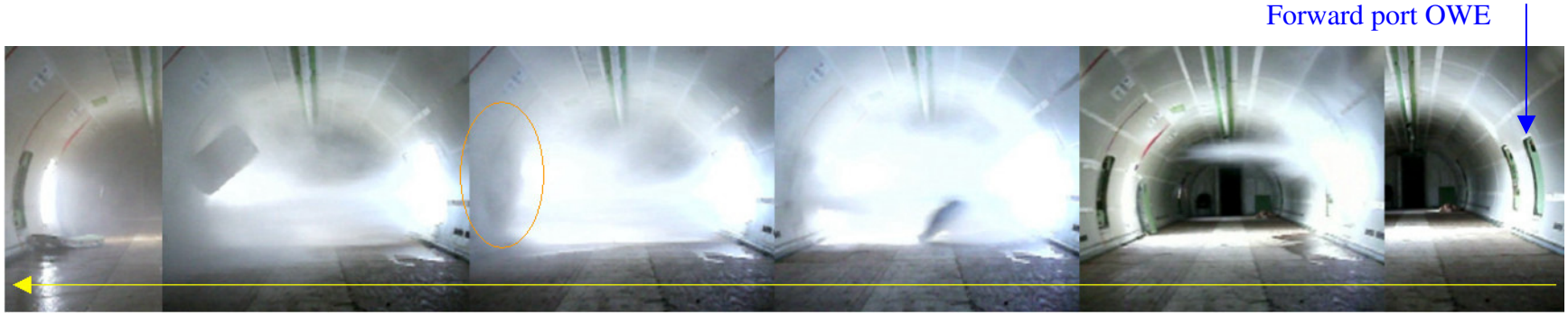
Figure 15: B737 OWE door water displacement test – external video stills with time stamps.

At 20 US gal/sec from a roof turret, the weight of water striking the door and presumably the exterior release panel is nominally 167 pounds (75.75 kg) per second (water density equals 8.345 pounds/US gal). In 0.44 seconds 8.8 US gallons (33.31 liters) would strike the release panel with a weight of 73.4 pounds (33.3 kg). The water pressure upon exiting the turret nozzle or at the fuselage surface is not known. The door, approximately 45 pounds (20.4 kg) in weight, was thrown to the opposite side of the fuselage.

3.2 B737 OWE DOOR TEST – INTERNAL VIEW

An interior view was recorded 18 Nov 2015, as part of a separate B737 OWE door water displacement test. A fire truck was positioned on the port side in front of the wing just inboard of the wing tip. A first attempt did not result in water contact on the forward port OWE external door release panel. On the second attempt, the door was displaced 5.96 seconds after the water pump started, shown in Figure 16. The OWE door travelled across the full width of the cabin and struck the opposite wall 0.57 seconds later (at 6.53 sec, circled) and then rotated up (6.76 sec), fell and was picked up again by the water stream such that it did not finally come to rest on the floor until 8.43 seconds. Water delivery lasted about 10 seconds utilizing approximately 200 gallons.

NOTE: The video camera was set up on a tripod at the front of the cargo hold looking aft to record the forward port OWE. Therefore the sequence of stills from the video, shown below, advance from right to left.



8.43 sec 6.76 6.53 6.26 5.96 Prior

Figure 16: B737 OWE door water intrusion test – internal video stills with time stamps.

The truck positions for the OWE water penetrations on the B722 are summarized graphically in Figure 17.

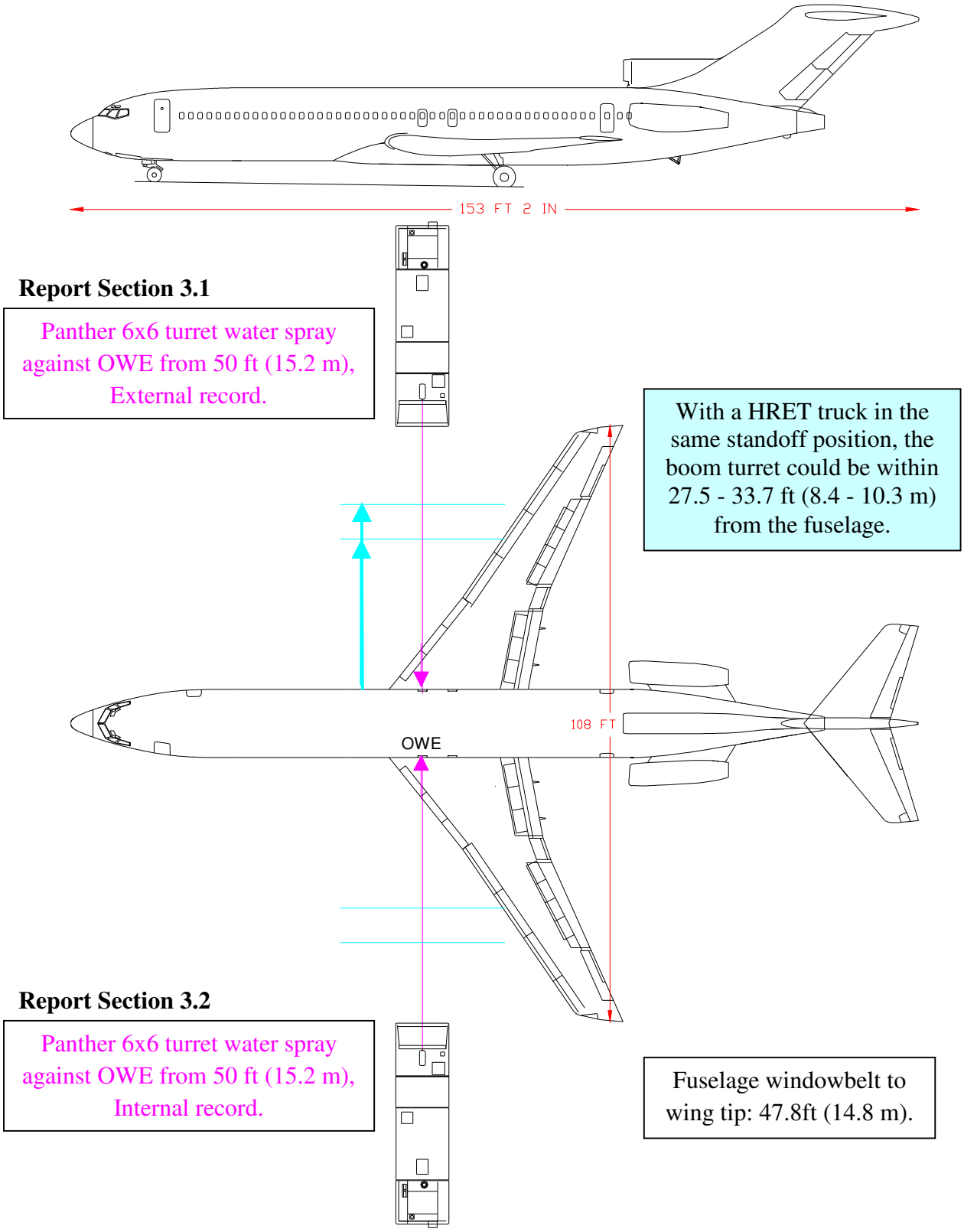


Figure 17: B727 OWE water penetration tests.

4.0 DISCUSSION AND SUMMARY

Many of the donated ARFF trainers in North America are cargo aircraft (84 B727s from FedEx for example [13]) with no cabin windows as they were blanked out when the original passenger aircraft was converted to a cargo interior. These training aids would typically have only their two forward OWEs operational.

B777 and 787 windows appear to be different from earlier Boeing models and their installation details are not completely known at this time other than that they retain a similar design philosophy.

Airbus cabin windows should not push in unless they have been shattered first, because the windows are held by an oval ring with six screws. Bombardier CRJ 100/200 and Global Express cabin windows have 31 bolts securing them to the fuselage skin; however, C Series windows are held by clips (7 aircraft in service, 274 on order [6]).

Type IIIB OWEs do not present a risk when operated by an external water stream as they cannot be projected into the cabin. The population of this type of door is increasing from the current level of 35% of the commercial transport fleet covered in this report.

Modern aircraft cabin interior cabin wall panels cover two window bays. These panels tend to be made of composite material, not aluminium. These wider panels will still be displaced, but the seats will prevent them from travelling as far as experienced with the single bay units on the B732. They may trap the displaced window panes – thus reducing the threat of injurious projectiles, but still pose a danger in terms of potentially providing oxygen to an internal fire and/or a fuselage entry point for external fire. The double-wide panels may also serve to diffuse the straight water stream into a finer spay that may be more effective at reducing the interior temperature, when considering this discovery as a potential ARFF tool, and may wet a wider area within the cabin.

The OIAA has already discussed modifying an area of the B722 such that two-bay cabin liners can be mounted, windows installed and water displacement tests carried out. The set-up would be next to a Type IIIA OWE, so that fire truck operators could practice on both types of water stream displacement.

The door release panels in a Type IIIB door are in the same location along the top edge as they are in a Type IIIA door and thus very close to the hinge line. Retrofitting a Type IIIB into the B722 may not be practical but tests should be carried out to determine if a specific technique is required to release the spring-loaded door. Possibly another airport ERS has a Boeing Next Generation (NG) training aircraft that could be used for further study.

Previous research on selecting fuselage locations for piercing with the Stinger on the one HRET truck in the OIAA fleet had led to guidance that operators should consider piercing the windows of an aircraft for easy and unobstructed delivery of agent to a main deck fire. Piercing tools lave a lower flow rate however, typically 250 gpm (946 lpm) that is delivered in a fan pattern rather than a straight stream. The proposed B722 modifications would also include a practice area for piercing with replaceable skin panels.

Those ARFF agencies equipped with a HRET often practice getting the head of their boom in through the L1 door (typical passenger entry Type A or Type 1) and streaming water from the tip turret into the cabin, as shown in Figure 18. This precision manoeuvring takes skill and time and risks delaying extinguishment, while risking damage to equipment on the boom tip.

Those airport services that have an HRET piercing tool seem to be attracted to fuselage piercing above the windowbelt, where there are no exterior visual cues to guide where to pierce and lots of potential internal structural obstructions to getting water into the cabin. A piercing hazard on B787s in this area is that the over-head luggage bins contain pressurized cylinders with breathing oxygen for passenger masks. Other aircraft may have impediments such as chemical oxygen generators in the passenger service modules on the bottoms of the overhead luggage bins.

Figure 18: HRET turret being guided into B727 through L1 door.

Very large aircraft make it difficult to loft water into the fuselage through the burned-through crown. The B777 crash in San Francisco illustrates the difficulty. Either penetrating intact cabin windows or flowing water through the burning (and shrinking) cabin windows may deliver firefighting agent more directly and efficiently to the inside of the fuselage, as shown in Figure 19a and 19b.

a) Water stream lofted over the top of the aircraft (arrow) from non-HRET ARFF truck

b) Water streams over structure (arrow), Cabin windows burning (circled)

Figure 19: Asiana FL 214, San Francisco. July 6, 2013 [14].

Reaching out with the HRET boom and first piercing the cabin window on an Airbus aircraft would result in similar capabilities as water stream penetration on aircraft with clipped windows. The HRET turret is located beside the piercing tool on the end of the boom, so the switch from piercing to full water stream flow through the broken window would be relatively quick. The B722 trainer aircraft modification could include a retrofit with an Airbus structure to allow exploration of this technique. The proposed ERS B722 window/OWE/piercing test area modification would divert all water flowed into the cabin and direct it overboard for collection and measurement.

The ARFF community would greatly benefit from a full review of all operational aircraft window and OWE door designs, summarizing which can be readily displaced by a typical fire truck turret or handline water stream.

Additional work/inquiry needs to be carried out to determine the applicability of this safety issue to other aircraft types. A survey of the worldwide civil airliner census for 2016 [6] shows that over 10,100 active Boeing aircraft have windows that are susceptible to being displaced by a direct water stream and roughly 7500 Boeing, 5200 Airbus, 900 ATR, 1300 Bombardier and 1100 Embraer currently active commercial aircraft have Type IIIA OWEs [6]. The majority of B737s in service are NG variants and the thousands of MAX versions on order will also have Type IIIB OWEs [6].

The NRC and OIAA ERS have engaged Transport Canada (TC) experts in aircraft emergency preparedness and ARFF to advise on the best approach to share the information nationally and internationally to first address the safety concern. Once the safety concerns have been properly addressed, the potential to use this new information as an ARFF tool will be more thoroughly considered.

Potential advantages of a new ARFF tool might include:

- Ventilation of a fuselage without having to send personnel to open a door or up a ladder to break a window;
- Delivery of up to 1200 gpm of agent into the interior rather than 250 gpm from a piercing tool;
- Delivery of large volumes of agent inside the aircraft quickly, without sending firefighters with a handline or difficult manoeuvring of the tip turret of a HRET through a door opening;
- Provide ARFF units without a HRET truck a slightly similar capability;
- Delivery of agent into a fuselage more directly, quickly and efficiently rather than trying to loft water in through the crown after it has burned-through; and,
- Delivery of agent into a composite fuselage where NRC/OIAA full scale aircraft fire tests have revealed the crown will not burn-through as quickly as in a traditional aluminium fuselage [15].

This work could potentially rewrite standard operating procedures from both the evacuee safety and firefighting perspectives.

5.0 ACKNOWLEDGEMENTS

Mr. R. Elmer of Ottawa volunteered many hours of his time before and during the tests to provide both video equipment and related technical support.

The authors wish to recognize OIAA ERS Firefighter Jean Francois Genest for creating the initial cabin window water displacement. This occurrence exposed a potential safety hazard and initiated a preliminary study on the applicability of water stream displacement.

6.0 REFERENCES

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[2] TP 14052 - Guidelines for Aircraft Ground - Icing Operations , Chapter 10 - Preventative Measures and De/Anti-Icing Procedures: https://www.tc.gc.ca/eng/civilaviation/publications/tp14052-chapter10-1816.htm#10_5
[3] Aircraft Exit Profiles https://www.tc.gc.ca/eng/civilaviation/publications/tp12296-schedulea-section2-5545.htm#section15
[4] Boeing 737 Flight Locks http://www.amevoice.com/blog/1035/boeing-737-flight-locks/
[5] https://www.dvbbank.com/~/media/Files/D/Dvb-Bank-Corp/documents/dvb-aviation-finance-commerical-aircraft-booklet-2015-2016.pdf
[6] World Airliner Census 2016, Flight International: http://pic.carnoc.com/vedio/2016/2016fleetreport.pdf
[7] Boeing ARFF Crash Charts: http://www.boeing.com/commercial/airports/rescue_fire.page
[8] OWE door images: https://aviation-safety.net/airlinesafety/exits/
[9] OWE release handle mechanisms: http://www.fdot.gov/aviation/pdfs/Aviation_Emergency_Response_Aircraft_Guidebook_compressed.pdf
[10] Bombardier aircraft Crash Charts: https://customer.aero.bombardier.com/webd/BAG/CustSite/BRAD/RACSDocument.nsf/vwWebPage/QuickLinks_EmergencyDocs?OpenDocument
[11] http://www.brandweerschiphol.nl/luchtvaart/instructie-aircraft-crash-recovery-guide/instructie-aircraft-crash-recovery-guide_pdf.html
[12] http://www.rzjets.net/aircraft/
[13] Retired FedEx Boeing 727s Dot The Globe: http://aviationweek.com/blog/interactive-map-retired-fedex-boeing-727s-dot-globe
[14] ABC News on Jul 9, 2013: https://www.youtube.com/watch?v=SAi6cRI-rq0
[15] LTR-SMM-2015-0414, Gould, Ron, Hind, Simon and Jacquet, Francois, “Full-Scale Aircraft Fire Tests - A Comparison of Aluminium and Composite Burn-Through” 6/30/2015.

APPENDIX A:
OVERWING EXITS

OWE door images and actuation information collected from [8, 9, 10, 11].

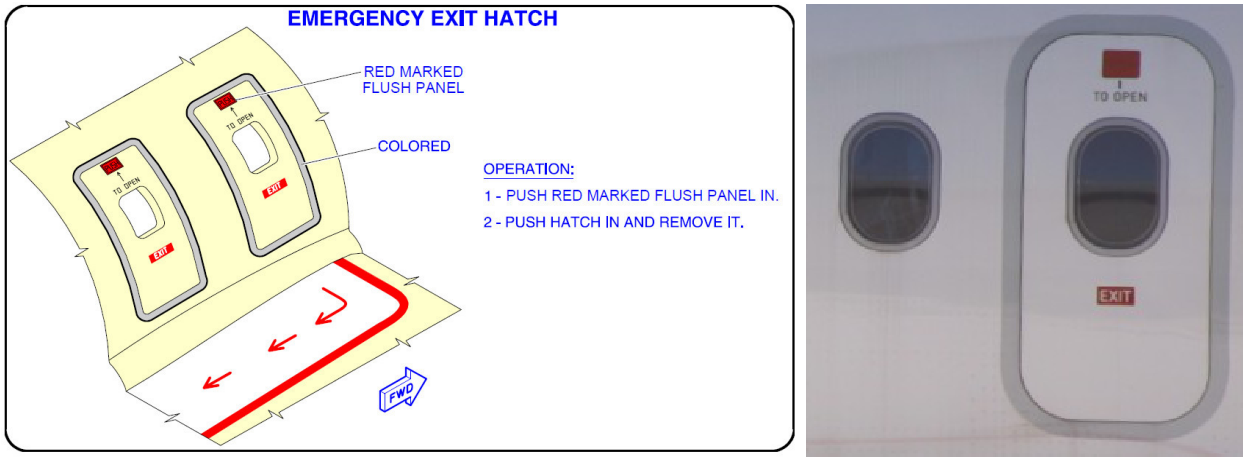
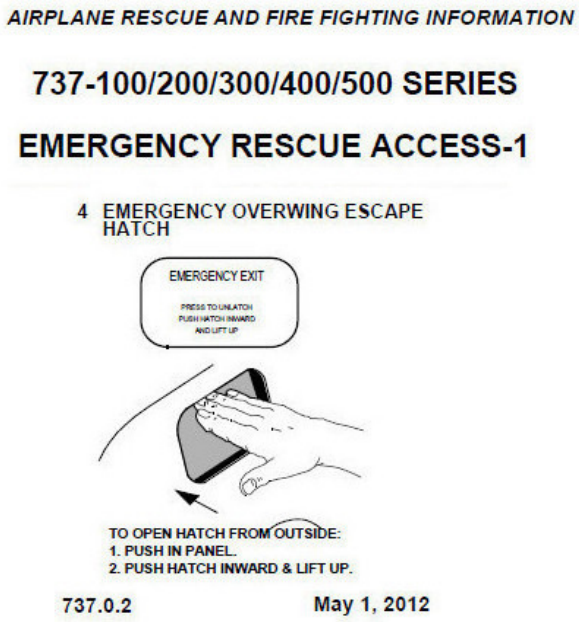
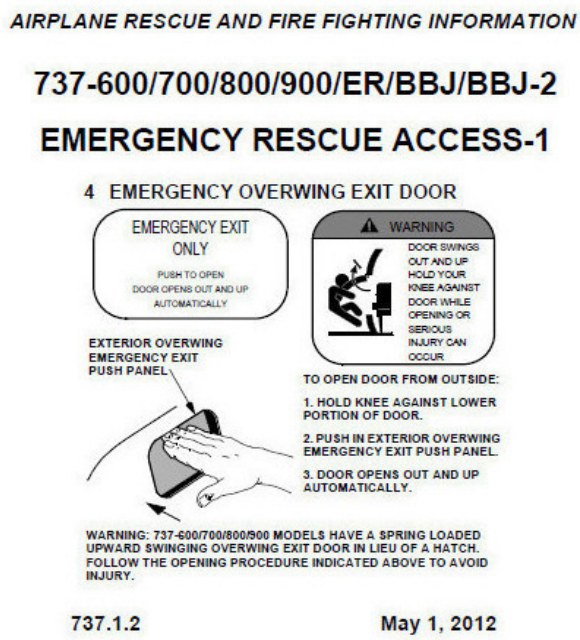


Fig. A-1 ARFF quick reference chart for exterior actuation of OWE for A320.



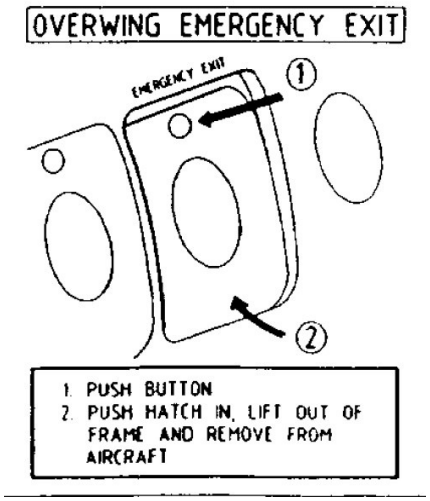
a) Type IIIA OWE



b) Type IIIB OWE (737NG)

Fig. A-2: ARFF quick reference chart for exterior actuation of OWE for B737s.

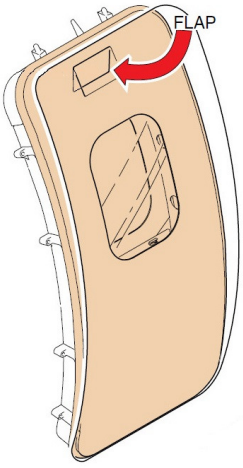
Boeing "Airplane Characteristics for Airport Planning" of Sept 2013 named '737.pdf' says OWEs for B737-100 to –500 are 20"W x 38"H and calls them Type II which does not fit the 14 CFR 25.807 description for Type II. It does not say what the –600 to -900 (NGs) are. BUT the same document says that B737BBJ and BBJ2 have Type III OWEs.



Fokker 70, 100

Dassault Falcon 2000/EX

CL-605

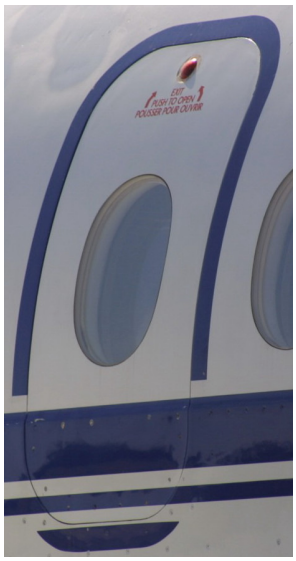


CRJ 700 to 1000, CL-600/1/4,650

Learjet 45

Bombardier C Series 100/300

Fig. A-3 Type IIIA OWEs that can be opened by a water stream.



Falcon 50, 900, 2000, 7X, 8X

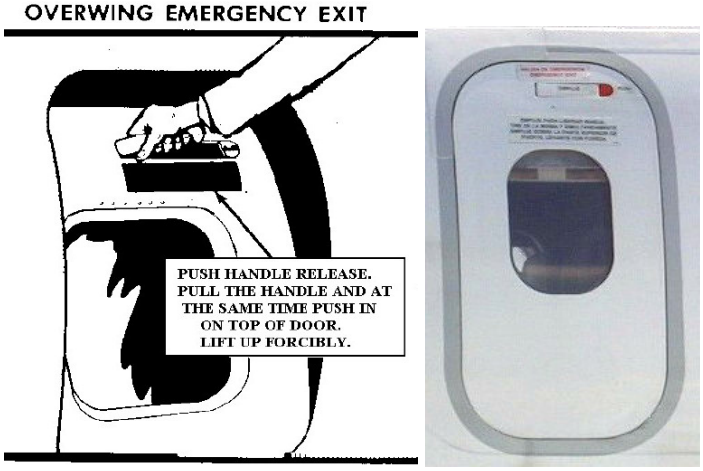
Hawker variants

The small size of the push-button release may prevent exterior actuation by a water stream if the stream becomes dispersed due to stand-off distance.

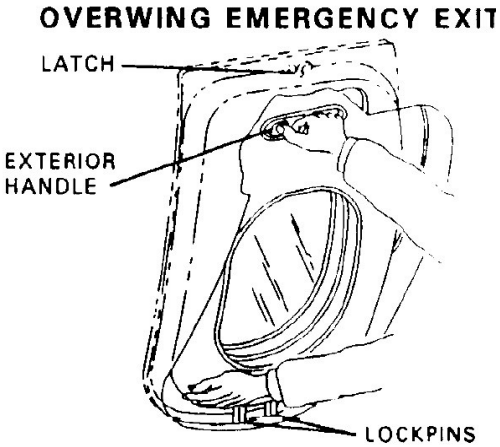
B757 and B767

The B757 and 767 exterior panel has an integral handle. It is not clear if this changes the operation compared to B737 aircraft OWEs.

Fig. A-4 Type IIIA OWEs that may be opened by a water stream.

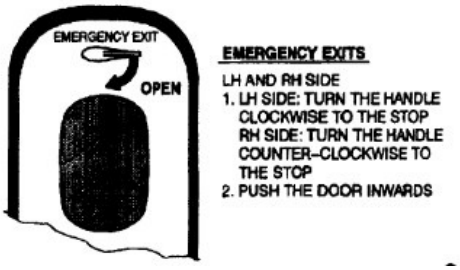


MD-83 and B717

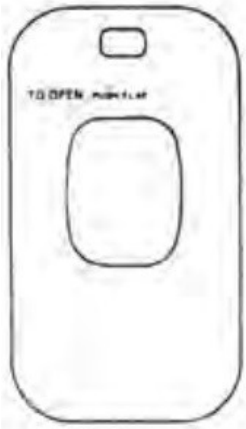


MD-90

Cessna Citation II



SAAB 340, 2000



C Emergency Escape Hatches

1 One hatch is found on each side just forward of the engines.

2 To open, push flap in, grab handle and squeeze.

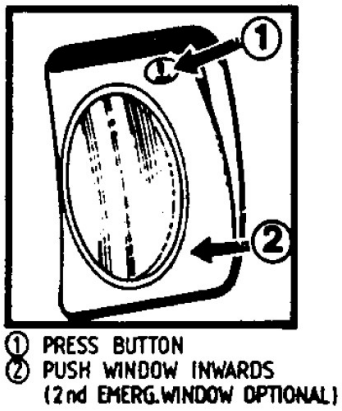
3 Exit is plug type in design and must be pushed into the fuselage

ATR-42 and 72

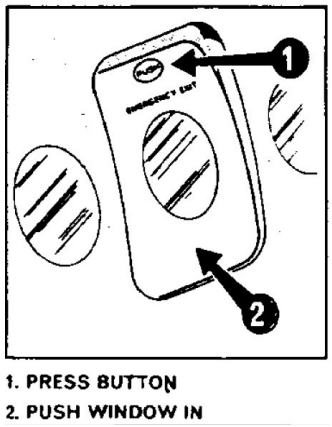
Dornier 328Jet

Fig. A-5 Type IIIA OWEs that require pulling and rotating a lever or squeezing an internal handle and therefore cannot be opened by a water stream.

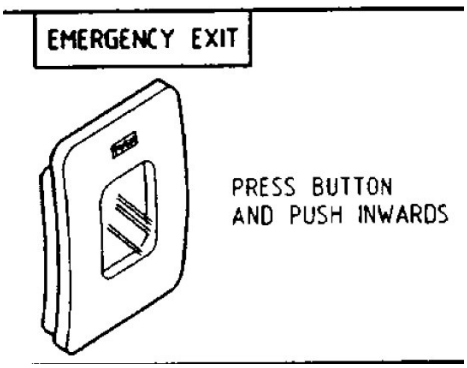
Emergency Exit Type IV. This type is a rectangular opening of not less than 19 inches wide by 26 inches high, with corner radii not greater than one-third the width of the exit, located over the wing, with a step-up inside the airplane of not more than 29 inches and a step-down outside the airplane of not more than 36 inches.



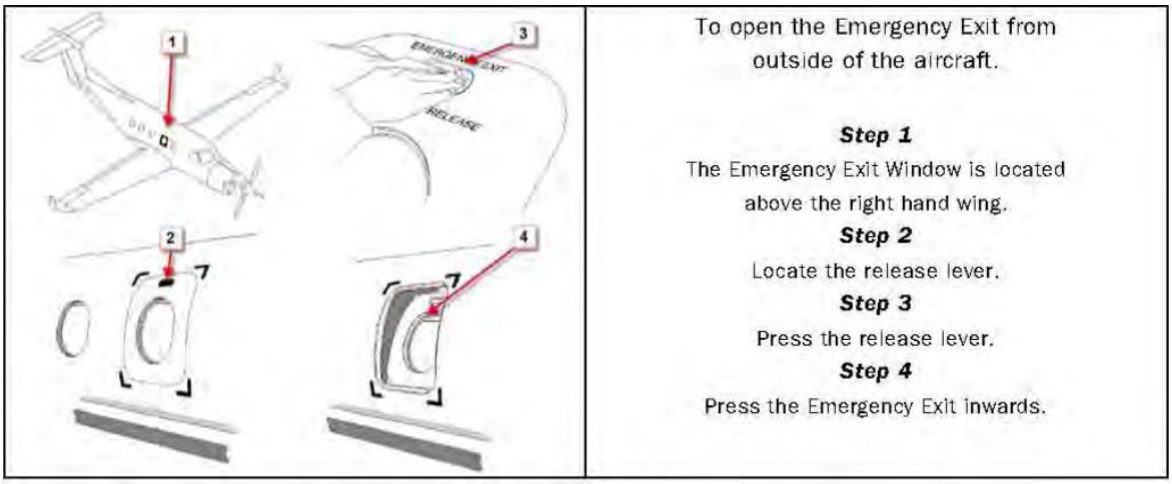
Fokker F27



Fokker F28



Fokker 50/60

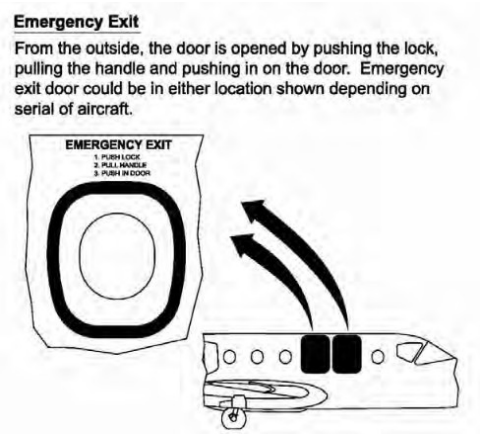


Pilatus PC-12, Type IV, Right side only

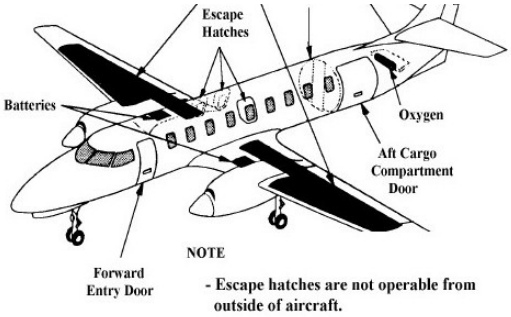
Fig. A-6 Examples of Type IV OWEs that can be opened by a water stream.

Learjet 35A

Beechcraft 1900



Beechjet 400



851 Fairchild Metro/Merlin aircraft were built and 225 were in airline service in 2016.
The three over-wing escape hatches are <u>NOT</u> operable from outside the aircraft except in rare cases.

Fig. A-7 Examples of Type IV OWEs that cannot be opened by a water stream.