AERAZUR

Aerosafety Systems Division

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PRELIMINARY STUDY on AIRCRAFT EVACUATION SYSTEMS AGING

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FOREWORD

Aérazur company, part of the Zodiac Group, has prepared the following “Preliminary study on aircraft evacuation system aging” under the French Direction Générale de l’Aviation Civile (DGAC) / Service de la Formation Aéronautique et du Contrôle Technique (SFACT) contract N° 00/07/SFACT/AEF.

This study will then be presented to a JAA Research Committee sub group, the “Occupant Survivability Project Advisory Group” (OS PAG), as part of the survival research program. The aim of the initial study is to define a future research program to prevent in service evacuation system failures in case of emergency. The continuing airworthiness of the equipment in service when aging would be the focus point of the future research program.

The study below basically consists of:

- Quick review of evacuation systems technology.
- Summary of regulations applying to evacuation systems.
- Presentation of maintenance recommendations.
- Analysis of practical aging cases considering the 3 above aspects: regulations, technology and maintenance.
- Present the structure and objectives of a possible further aging study.

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INTRODUCTION

Slides and slide rafts are used on most civil aviation aircraft to evacuate occupants in case of emergency. Their classic construction is an inflatable structure, a reservoir of compressed gas, an inflation system (aspirator & hose) and an aircraft interface.

Evacuation systems cover slides and slides raft. The main differences between these two products are:

- A slide has for function to evacuate aircraft occupants from the aircraft doors or overwing exits onto the ground. If the aircraft has ditched, the slide can be used as a flotation device. The evacuees can then grab a lifeline located around the slide.

- A slide raft has the ground evacuation function but in addition it has the raft function. Therefore the slide raft needs to have better air retention characteristics, have sufficient flotation for its passenger capacity, have two redundant inflated chambers, offer shelter from water and have a roof, be fitted with locating means, heaving ring, sea anchor and a survival kit.

When it comes to aging, the most sensitive component is the inflatable structure. Typically a fabric, nylon coated with neoprene or urethane to have airholding capacity, is used. Panels of this fabric are cut to specific dimensions and assembled together using cement, a chemical compound.

Evacuation systems are maintained on condition and manufacturers suggest maintenance interval and test procedures. Aérazur and Air Cruisers Company (both members of the Zodiac Group) as manufacturers but also through their product support and repair station experience feel that continuing airworthiness of aging evacuation systems could be studied. The study of aging evacuation systems would provide data from which measures can de determined.

Experience shows that climatic environment, operational conditions and maintenance practices have an impact on evacuation systems aging, life and proper function. These factors could be studied to maximize safety.

This preliminary study first gives the reader a presentation of what an aircraft emergency evacuation system is.

Additional background on evacuation systems is given by covering the European and American regulations.

Then, the reader's education on evacuation systems continues by covering industry situation, the design and the major constrains seen by the system.

Presentation of evacuation system manufacturers maintenance recommendations, analysis of failure modes and review of repair station experience and of some incidents then allow to identify future research areas.

Additional background on emergency evacuation incidents is also briefly discussed by commenting on the recent study from the American National Transportation Safety Board (NTSB), NTSB/SS-00/01 and its following recommendations.

Some operational recommendations and maintenance concerns which may affect evacuation system aging and continued airworthiness are then raised.

Conclusions are then drawn as to what research Aérazur and its sister company Air Cruisers could perform in the future to contribute to an industry effort to always improve reliability and ensure continuing airworthiness of aging evacuation systems.

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1- Presentation of Evacuation Systems

1.1 Actors in the Industry

Nowadays there are two actors in the aircraft evacuation system industry.

- Aérazur (France) and Air Cruisers (New Jersey, USA) are sister companies both member of the Zodiac Group (France). The Zodiac Group, also known for its inflatable boats, is mostly an aeronautical group. It is the parent company of Sicma (France) and Weber (USA) aircraft seat manufacturers, Monogram (USA) sanitation systems and recently acquired Intertechnique (France).
- Goodrich (Arizona, USA) known among other things for its aircraft wheel and brakes also has an emergency evacuation system division.

The market for emergency evacuation systems for civil commercial aviation is split about evenly between Aérazur/Air Cruisers and Goodrich.

Smaller companies that were manufacturing evacuation systems such as PICO (USA) were absorbed by other manufacturers.

RFD (United Kingdom) remains a very small actor in the industry. It produces the Concorde evacuation system.

Note that actors in the aircraft emergency evacuation system field usually manufacture other aeronautical inflatable safety products such as life rafts, helicopter floats and life jackets for civilian and military applications.

1.2 Description and Operations of Emergency Evacuation Systems

Basically, an aircraft emergency evacuation system is made of a compressed gas reservoir that inflates an airholding structure: the inflatable. A regulator positioned between the reservoir and the inflatable aims at optimizing the efficiency of the aspirator which sucks, by venturi effect, atmospheric air into the inflatable using the compressed gas flow.

1.2.1 Slides and Slide/Rafts

There are two main categories of inflatable aircraft evacuation systems:

- Slides which have for function to evacuate aircraft occupants from the aircraft doors or overwing exits onto the ground.
- Slide/Raft which have the slide function but can also be used as a raft in case of ditching. The raft mode main additional functions are to offer shelter from water and elements, to be fitted with locating means and a survival kit.

A321 Evacuation Slide

1.2.2 Location on Aircraft

When not in use evacuation systems need to be compactly packed and fitted next to the exit they are intended for.

1.2.2.1 Door Mounted Evacuation Systems

For door exits, the evacuation system can be mounted on the lower part of the door.
This is the case of most evacuation systems in service.

B777 Slide Raft fitted on a door.
“Bustle” or “decorative cover” is removed to show the evacuation system

1.2.2.2 Location below the door

On the A321 doors 2 and 3 the evacuation system is fitted in a composite container that is fitted in a cavity of the fuselage. The door and outer surface of the container constitute part of the aircraft skin. This installation frees up the door from the system weight and some space in the cabin. It also allows very good locking in place of the inflated slide. However, there is some structural penalty for the aircraft as an extra “hole” is added in the fuselage in the door area.

Note that this installation results in the slide being in the non-pressurized part of the cabin. This may affect aging of the slide but there is not enough program history to say so.

1.2.2.3 Off wing configurations

There are two ways to evacuate from the wing:

- from the trailing edge near the fuselage (flaps down) (ex: A320)
- from the leading edge, usually after the inboard engine (ex: MD11).

The slide or slide raft has to be combined with a ramp that guides the evacuees from the overwing exit onto the wing towards the sliding lane(s).

A320 Off Wing Slide

1.2.3 Operations

If an aircraft exit is unarmed, the evacuation system remains in its storage position.
When the exit is armed, the evacuation system deploys when the door or hatch is opened. The system typically deploys in 3 to 6 seconds.

1.2.4 Summary

For a more detailed description of slides and slides raft, including sketches, leading particulars, functions and operations, refer to Appendix A and B. These are extracts from the Component Maintenance Manual (CMM) of the A320 forward and aft slides and B777 forward door slide raft.

1.3 Evacuation System Technology

1.3.1 The Technological Challenge

The description given above may lead to believe that an evacuation system is simple. It is true that the principle is however the system complexity and that of its technology is significantly effected by the constrains imposed by its use on an aircraft. This includes:

- mass
- packed volume
- inflation time
- outside environment (especially temperature)
- reliability
- time in service

It should be noted that in addition a given evacuation system is rarely used during its life. When it is used it may be in adverse crash conditions which put additional reliability pressure on the system.

1.3.2 Inflatable Construction

Of the components of an emergency evacuation system, we will, in this study, mostly speak of the inflatable. This is because the other items are more classical mechanical parts which aging characteristics are well known and shared by many industries.
This would concern, the valve, the hoses, the composite parts, the aluminum aspirators, the brackets, release mechanism and the reservoir with its life limit. Consumable components such as o-rings, batteries and some survival kit parts are regularly replaced before they could become an aging issue.

1.3.2.1 Inflatable fabric

The inflatable fabric is one of the key material of the inflatable. It must be airholding, lightweight, high strength and meet radiant heat requirements.

Inflatable fabric has for base a nylon cloth. This material is coated on both sides with polyether based polyurethane or neoprene.

The coating on one side gives airholding properties. It is yellow in color. This side of the fabric will be inside the constructed inflatable structure.
On the other side the fabric is coated with a thin aluminized compound that provides radiant heat properties or coating which requires aluminized painting.

The inflatable fabric is qualified per TSO C69 (see details below). It is regularly tested in production to make sure it meets its specifications: an internal document based on the minimum TSO requirements and agreement with the supplier.

1.3.2.2 Sliding surface fabric

This fabric does not have to be airholding like the inflatable fabric. However, specific requirements are:

- high mechanical strength both in traction and tear resistance
- high bonding/cementing properties on the inflatable structure (to bear evacuee load)
- coating electrical conductivity to eliminate static electricity build up when used
- low friction
- light weight and flexibility.

The construction is a nylon cloth woven for high mechanical resistance. It is coated on one side with a low friction, conductive polyurethane compound on which evacuees slide and on the other side with a silver-gray reflective compound.

Previous technology fabrics are little by little disappearing from the field.

1.3.2.3 Other fabrics

Other fabrics may be used in the inflatable construction. The main one is the fabric used to manufacture the girt. This fabric has got to have high mechanical resistance as it bears the load of the evacuation system attachment to the aircraft.

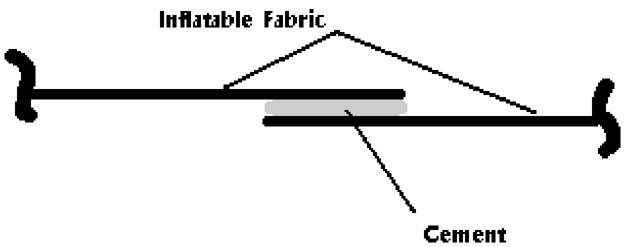
This heavier fabric uses similar coated construction as the inflatable fabric but uses a heavier cloth woven differently as well as conductive coating.

1.3.2.4 Cement and seam assemblies

Cement is another key component of the inflatable. It needs to give structural integrity and airholding properties to the structure.

An inflatable is constructed of fabric panels that are cut to specific dimensions. These panels are assembled together using cement. The bonded area is called a seam.

There are various assembly methods and seam types. A typical example of seam type is ¾ inch overlap below:



¾ inch overlap seam

Needless to say that the chemical and physical properties of the fabric/cement pair are defined by specifications and checked by tests: peeling, shear, tensile strength, accelerated aging…

Technologywise, the issue is that the choice of chemical components (polyurethane – polyether/ polyesther base) is again a compromise. We may give as example the humidity resistance characteristics (hydrolysis), the compatibility with long seams (drying / activation time), storage properties and aging (evolution of chemical bond over time).

1.3.2.5 Reflective coating

Seams that are fabricated with radiant heat reflective fabrics are overcoated with a polyurethane reflective coating compound that contains aluminum platelets.

As a final note we can say that operating conditions of –40°C to +71°C, weight and space contribute, for example, to the technical challenge of inflatable construction and fabric technology.

1.4 The future challenges

Today's largest civil evacuation systems are Goodrich B747 upper deck single lane slide, for its length, and Air Cruisers Company B777 slide raft, especially the forward door, for its overall size. Air Cruisers Company MD11 overwing ramp/slide raft is also a bulky system that can be disconnected into 2 sub-systems.

The biggest of regional jets to come from Embraer, Fairhild-Dornier will require an emergency evacuation system. However their design will not be a major technological challenge as the evacuation heights involved have been dealt with in the past.

The future challenge will come from superjumbos such as the A380 or the B747X if it is developed. The lower deck of these aircraft would be close the existing B777. However, the upper deck to be fitted with slide rafts at a normal door sill height of about 8 meters is quite a challenge for the evacuation system manufacturers. Goodrich was selected to design and manufacture the A380 evacuation system.

The A380 evacuation systems will undoubtedly face reliability and aging requirements more stringent than for the previous generation of aircraft.

2- Regulations for Aircraft Evacuations Systems

2.1 Overview of Requirements

There are 3 main categories of requirements used for evacuation system design and operations:

- the FAA Technical Standard Order (TSO) C69 defines mostly performance criteria.
- the FAR and JAR 25 covers airworthiness standards.
- the FAR 121 and JAR OPS 1 defines operating requirements.

The regulations governing the evacuation system reservoir are also covered below as it gives an example of how the aging issue is controlled with regulations.

2.2 TSO-C69

2.2.1 Introduction

The FAA Technical Standard Order C69 (TSO-C69) is the main airworthiness authorities document governing slide design. It is a standard providing the minimum performance for inflatable emergency evacuation slides, overwing exit ramps, ramp/slides, and slide/rafts.

2.2.2 History of the TSO-C69 requirements

This document has evolved over time. It is currently at revision c effective 18 August 1999. A copy of TSO-C69c can be found in Appendix C.

The history of this standard can be summarized as follow:

- Emergency evacuation slides approved before 15 Aug. 1961 were certified with the aircraft and did not respond to specific TSO requirements.

- TSO-C69 original issue was applicable 15 August 1961. It was put together mostly by FAA and Boeing certification personnel and laid ground for evacuation system standards.

- TSO-C69a was issued 3 June 1983. The major item of this revision was the introduction of a radiant heat requirement (in case of fire).

- TSO-C69b was issued 17 August 1988. One of the main additions was the puncture proof requirement for off wing slide ramp floor fabric.

- TSO-C69c was issued 18 August 1999. The main changes are:

- the increase of evacuation rate from 60 to 70 passenger per minute per lane
- the addition of a beam strength test to accommodate 3 evacuees sliding down bunched together.
- The requirement of actual testing in the dark of night with naive subjects to test the lighting system efficiency.

Note that today slides and slide/rafts approved under previous revision of the TSO can still be manufactured under their previous TSO after authorization per 14 CFR title 21.

Evacuation systems currently in development phase such as those for the A380 would have to meet the latest TSO-C69c requirements.

2.2.3 Non-age related requirements of the TSO-C69c

Generally speaking the TSO is written so that all sub-assemblies and the system are reliable, allow a safe evacuation in common crash conditions and be easy/intuitive to use.

The main non directly aging-related subjects covered in TSO-C69c are:

- The seam strength (§3.1.6 & §3.1.7).
- The canopy properties such as strength, wind resistance, waterproof (§3.1.8)
- The flammability and radiant heat resistance requirements (§3.1.9 & §3.1.10). Note that the radiant heat resistance requirement historically is the reason why emergency evacuation systems color changed from yellow to silver gray.
- The requirement for the system to be easy to operate (§4.1) and function between –40 to +160 degrees F and even –65 degrees F if installed in the non-pressurized part of the cabin (§4.2).
- The beam strength must allow the evacuation system to evacuate 3 evacuees bunched together (§4.3.1) and strongly be attached to the aircraft (§4.3.2).
- The slide construction must not allow static electricity build-up that could ignite spilled fuel (§4.4) and be usable even when partially or totally deflated (§4.5).
- The slide length must allow safe evacuation with the landing gear extended or damaged (§4.6) and it may be fitted with a device to reenter the aircraft after evacuation (§4.9).
- The evacuation rate must be at least 70 evacuees per minute per sliding lane (§4.10) and consider a night-evacuation.
- Automatic inflation to full erection with a manual backup is required in 6 seconds, except for ramp/slide and off wing slide systems which are allowed 10 seconds to deploy (§4.11 & §4.12).
- Dual sliding lane devices must allow parallel and simultaneous escape path (§4.16), while evacuation system design must prevent evacuees to fall for the device (§4.17).

- Wind performances (§4.20) require the system to deploy and operate in 25-knot winds and to be usable in adverse weather condition including rain (§4.21).
- Inflatable pressure retention requirements are covered in §4.23 to §4.25
- The raft properties of the evacuation system including the capacity, buoyancy and safety devices (§4.26 to §4.43).

2.2.4 Age related requirements of the TSO-C69c

When it comes to aging of inflatable evacuation systems the TSO currently says that:

- Nonmetallic parts used in the manufacturing process cannot be more than 18 months old (§3.1.2).
- Nonmetallic materials must not support fungus growth (§3.1.3).
- Nonmetallic materials must resist to fuel, oils, hydraulic fluids and seawater (§3.1.4).
- Coated fabrics must retain 90% of their physical properties after accelerated aging tests (§3.1.5). Properties include:
    - strength
    - adhesion
    - permeability
    - hydrolysis
- Metallic parts must resist to corrosion (§3.2)
- Inflated and load carrying fabrics need protection from chafing and abrasion (§3.3)
- Sliding lanes can accommodate use by at least 200 evacuees (§4.21.2)

All test protocols and success criteria can be found in section 5 of the TSO-C69c in Appendix C.

2.3 FAR & JAR Part 25

2.3.1 Introduction

In addition to the FAA TSC-C69, the inflatable evacuation system performances are also defined per the FAR 25 (Transport Category Airplanes). Title 14 of the Code of Federal Regulations (14 CFR) Emergency provision section. The same section of JAR 25 (Large Airplanes) contains very similar requirements. The two texts differ by minor differences, some slight wording changes such as dimensions in millimeters and regulation cross-references. JAR 25 currently (August 2000) at change 14 is scheduled to be revised to change 15 which may bring it inline with FAR 25 in particular for §25-810.

2.3.2 FAR & JAR 25 requirements for evacuation systems

The regulation paragraphs of the "Emergency Provision" section effecting evacuation systems can be found in Appendix D. A summary of their content is outlined below:

2.3.2.1 Ditching (§25.801)

Regarding evacuation systems, this paragraph refers to the ditching provisions in FAR/JAR 25-807, 25-1411 and 25-1415. These regulations typically define some raft mode requirements and say that slide and slide rafts must be stowed by the exit they are intended to be used at.

2.3.2.2 Emergency evacuation (§25.803)

This section calls for emergency means allowing rapid evacuation of passenger and crew considering extended and retracted landing gear positions and a possible fire.
It also calls for proof by testing and analysis during certification that the evacuation of all occupants to the ground can be achieved in 90 seconds using half of the exits in dark outside conditions. The detail of emergency demonstration requirement is found in Appendix J to Part 25.

2.3.2.3 Emergency exits (§25.807)

This section defines the emergency exit geometry and requirement according to the number of passengers. Ditching provision and crew evacuation are also covered. There is no specific requirement for evacuation systems defined here.

2.3.2.4 Emergency exit arrangement (§25.809)

This section covers exit operations including easy opening. There are no evacuation system requirements here but the opening of the exit (door or hatch) typically initiates the evacuation system deployment.

2.3.2.5 Emergency egress assist means and escape routes (§25.810)

This is the main regulation section that is used to define evacuation systems requirements in addition to the TSO-C69.

As the entire 25.810 is related to evacuation system design, the best here is that the reader refers to the copy in Appendix D. However, the requirements and their design consequences can be summarized as follow:

2.3.2.5.1 Evacuation means requirement (Evacuation height)

Evacuation assisting means must be fitted to exits higher than 6 feet from the ground landing gear extended. For door exits that means 6 feet from the ground to the door sill the door sill, for the overwing exit it means 6 feet from the flap in the takeoff or landing position whichever is higher. This in itself is not a major technical challenge.
However, there is also a requirement for the evacuation system to provide a safe evacuation to the ground even with some landing gear collapse. This means that the slide usually end up being longer than what is required from a standard extended gear configuration. Indeed the door sill height can be higher than its normal value in case of a partial landing gear collapse or in the "tail-tip" condition

due to the center of gravity of a airplane it contacts the ground with its main landing gear and its tail leading to very high door sill height for the forward door for example. This increased slide length in turns increases the mass and bulk of the evacuation system which is in contradiction with other evacuation slide design requirements.

2.3.2.5.2 Self supporting and wind requirement
The evacuation slide must be self supporting and able to deploy and remain usable with the help of only one person in 25 knots winds from the most critical angle. This requires the slide to have a lot of what is called “beam strength” or rigidity and load bearing. This typically leads to a compromise of inflatable tube diameter and operating pressure.

2.3.2.5.3 Number of sliding lanes
Evacuations systems fitted to exit types A & B are required to have to parallel sliding lanes. Note this is only valid for type A exits in the JAR.

2.3.2.5.4 Automatic deployment and manual backup
The evacuation system must activate and deploy automatically in case of emergency. This typically happens when the exit is in “armed” mode and opened from the inside. The system should not deploy when the exit is open from the outside for obvious injury risks and deployment issues.

2.3.2.5.5 Deployment time
The evacuation system is required to be erected in 6 seconds after the deployment is begun. There is an exception with evacuation systems at type C exits which have 10 seconds to be erected. In the JAR, 10 seconds is given for all type of exits.
This typically requires an efficient inflation system with aspirator or another type of device to suck atmospheric air into the inflatable. The deployment sequence control is also impacted especially as you have to inflate not only fast but also in windy conditions.

2.3.2.5.6 Overwing evacuation requirements
Overwing exit requirements are similar to door exits, however in practical terms the slide geometry, the evacuation system storage location and the means to guide evacuees off the wing typically add design constraints.
When it comes to aging typical consequences are that overwing exits may be in non pressurized parts of the cabin (like on the A320 for example) and therefore more exposed to extreme environment conditions. The overwing configuration impacts slide geometry. It usually leads to a more complex construction for the inflatable increasing the number of seams.

2.3.2.5.7 Miscellaneous
§25.810 also covers crew evacuation rope that is not related at all to this study.

Again it should be noted that all the above requirements of the FAR/JAR 25 Emergency provision section do not directly refer to aging but their combination forces manufacturers to use technological solutions that like any other for a manufactured product are subject to aging. Regulations constraints are cumulated with aircraft manufacturer ones such as volume and weight.

2.3.2.6 Emergency Lighting (§25-812)
Paragraph (h) relates to evacuation systems and requires that the evacuation system be illuminated to show the egress path. In practical terms the lights may be fitted on the system itself or exterior lighting from the aircraft.

2.4 Operating requirements

A copy of the operating regulations outlines in this section can be found in Appendix E.

2.4.1 FAR PART 121

FAR 121.310 Additional emergency equipment covers the 6-foot rule and the exception to that rule (see Part 25.809 & 25.810).
FAR 121.339 Emergency equipment for extended over-water operations covers among other things needs for rafts and slide/rafts on board an aircraft.

2.4.2 JAR OPS 1

JAR-OPS 1.805 covers the need for an emergency evacuation according to the door and overwing exit height from the ground. It is equivalent to the 6-foot rule defined in FAR/JAR 25.810 with one major exception introduced recently.
"for [aircraft] which a Type Certificate was first applied for on or after 1 April 2000, would be more than 1.83 meters (6ft) above the ground after the collapse of, or failure to extend of one or more legs of the landing gear, there must be a device to assist all members of the flight crew in descending to reach the ground safely in an emergency."
What this new requirement means it that some of the Regional jets to be introduced in the coming years may have to be fitted with evacuation system which would not the case for a similar aircraft for which a Type certification was applied before 1 April 2000. That will to some extend increase the world fleet of aircraft fitted with evacuation systems. This may contribute to justify a preventive study on aging of such systems.

JAR OPS 1.830 – Life rafts and survival ELTs for Extended Overwater flights defines requirements for rafts and slide rafts. This does not directly relate to evacuation system aging.

2.5 Reservoir Regulations

The USA Department of transportation (DOT) Code of Federal regulations (CFR) Title 49 – transportation covers regulations for compressed gas cylinders used in various industries including those fitted in evacuations systems. Among the title, Section 173 and in particular 173.34 gives inspection and test requirements.

Reservoir is the only major component of evacuation systems which is governed by regulations imposing a fixed time between overhaul and life limit.

Steel reservoirs used on older generation systems typically have a life of 24 years from date of manufacture are hydrostatically tested around 5000 psi (5/3 of operating pressure of 3000 psi) every 3 years.
In more recent years lighter cylinders have been developed. They typically use an aluminum liner reinforced with composite fiber wraps of Kevlar® or Carbon fiber and epoxy. Kevlar® reservoirs have a 15 year life limit. Carbon reservoirs could see their current 15 year life extended to 25 years. | 9 April 2002

Details on hydrostatic test procedure can be found in the Compressed Gas Association (CGA) pamphlets.

There is no aging issue with cylinders due to the conservative and industry/authority controlled life limit.

3- Aging and Failures of Evacuation Systems

3.1 Introduction

There are many factors that affect the life of evacuation systems. Among the obvious ones based on Aérazur/Air Cruisers' experience as a manufacturer and repair station are:

- the environment (humidity and heat)
- the aircraft type and door (protection from environment)
- the maintenance practices

There is no way (whatever the product manufactured) to predict the exact failure date and time. Failures or continued airworthiness can be predicted if handling measures are taken, certain signs looked for and tests performed. This is how are based our maintenance recommendations which are updated based on the field reports we get. There is no life limit, the equipment is maintained "on condition".

When units are maintained at the manufacturer, we recommend (on a case by case basis) the replacement of the equipment based on tests and its condition. In their CMMs, manufacturers give tests to perform during maintenance to see if a unit is still fit for service. Tests enforcement at operators and maintenance center is outside of manufacturers control. Lastly, based on experience manufacturers have reached a consensus that the maintenance periodicity should be reduced from three (3) to one (1) year when the evacuation system reaches 15 years of age.

3.2 Maintenance Recommandations

3.2.1 Maintenance on condition

As stated above, historically there has never been a life limit on aircraft evacuation systems. Only the reservoir sub assembly has a life limit based on the USA DOT regulations. This limit can be 15, 24 or 25 years depending on the reservoir technology used.

The equipment is maintained on condition and maintenance recommendations are given in the equipment CMM.

3.2.2 Industry consensus

3.2.2.1 Maintenance periodicity

Evacuation system manufacturers, Aérazur/Air Cruisers and Goodrich, have reached the same conclusions on the recommended time between overhaul.

A 3 year periodicity is recommended until 15 years of age. After 15 years, the periodicity is reduced to one year.

The initial three year interval is based on the DOT requirement to hydrostatically test the reservoirs. As the system has to be removed from aircraft for that test, the opportunity might as well be used to perform a system overhaul. Note that the evacuation system sub assemblies (such as survival kit, valves, batteries…) are designed to meet or exceed that periodicity allowing some storage time.

The switch to one year is based on field and repair station experience as well as testing on some units returned by operators at a fixed age. This is an average value fixed on the safe side.
This measure does not satisfy all operators, some may have to scrap inflatables or units prior to 15 years while others feel that the unit could go from 15 to 18 years without maintenance.
These claims are sometimes justified as equipment age at different rate according to their environment and operations. Better understanding and quantifying the aging process is the focus of the proposed future study. In the meantime it is best to have a safety oriented approach and conservative recommendation.

Documents reflecting the industry maintenance interval recommendations can be found in Appendix F: Air Cruisers Company S.I.L 25-98 Rev 2 dated 28 Jan. 1997 and Goodrich Newsletters 25-163 dated 12 Nov. 1999.

3.2.2.2 Maintenance tasks

The main maintenance tasks can be summarized as:
- Functional test on aircraft or in the shop
- Inflatable overpressure and leakage test (see below)
- Hose integrity verification (incl. hydrostatic test)
- Light system test (if applicable)
- Disassembly and checks of sub-assemblies
- Incorporation of S.B and S.I.L as applicable
- Reservoir and valve assembly maintenance (incl. hydrostatic test)

The two major tests for the inflatable are:
- the overpressure test which consists in inflating for a limited time the inflatable with a pressure above the maximum operating pressure to check the seams and assembly integrity.
- the leak test which consists in inflating the inflatable at a given pressure within the operating range and to monitor the pressure drop after a certain time (minimum of 4 hours) compared to a reference curve. This allows to check the airholding characteristics of the inflatable.

Some repairs, such as patching of leaks, are acceptable but a unit is considered airworthy only if it successfully passes the two tests. Note that repairs to the inflatable are systematically checked by performing the above tests.

In service issues also lead to the increase of maintenance checks. For example aging of sliding lanes and field issues lead to Goodrich Newsletters 25-160 in Appendix G.

3.3 Failure Modes

We will mostly talk here about the inflatable failures. The other components of an evacuation system may also fail due to age or handling for example, but the failure modes and corrective actions for mechanical parts such as aspirators, valves or composite/metallic packboards are known in the industry.

3.3.1 Non age related failures

Non age related failures are typically due to incidents during deployment or handling issues and may result into non repairable damage. Examples are:

- inadvertent deployment into stairways
- tempering with door motion during inadvertent deployment
- dragging unit on the floor after aircraft inflation trial
- scheduled deployment procedure issues
- deployment of a unit previously punctured (leading to a tear)
- bad packing or maintenance (see below)

3.3.2 Age related failures

There are various types of aging damage of inflatables among which:

- fabric porosity: chafing, abrasion, holes (general wear)
- hydrolysis
- fabric delamination
- seam failure
- fluid contamination

3.3.2.1 Porosity

Porosity is characterized by air leakage through the fabric. There is no repair scheme for wide areas of porosity (for example resulting from chafing). Typically a porous inflatable is rejected as it does not pass the leak test. The older the unit the more subject it is to porosity and general wear due to repeated mechanical constrains and possibly loss of mechanical properties of the fabric.
During deployment an inflatable touched by porosity would leak which could impair its function depending to the leak rate and duration of evacuation.

3.3.2.2 Hydrolysis

Hydrolysis is the deterioration of fabric coatings by exposure to humidity and moisture. The coating takes a rubbery aspect. Some panel replacement can be attempted by the OEM but typically system showing signs of hydrolysis have general fabric deterioration that requires a complete inflatable replacement.
During deployment an inflatable touched by hydrolysis would leak which could impair its function depending to the leak rate and duration of evacuation.

3.3.2.3 Fabric Delamination

Fabric delamination is the separation of coating from the nylon cloth. It may be a consequence of hydrolysis but it is also sometimes found in old units that do not show excessive humidity exposure.
This type of failure in case of deployment would lead to a pressure loss. The pressure loss rate depends on the extent of the inflatable fabric delamination. Delamination of floor fabric may lead to the evacuee puncturing the sliding surface which may render the slide unsafe or unusable.

3.3.2.4 Seam Failure

Seam failure is the loss of bond between fabric panels in a cemented area. This phenomenon is mostly diagnosed during the overpressure test. This type of failure if happening during deployment leads to a pressure loss. It may render the system unusable or only usable as an apron. Again the leak rate due to the seam failure will define how long it takes for the slide to loose its beam strength and self supporting properties. Raft function could be lost if both chambers are effected.

3.3.2.5 Fluid Contamination

Fluid contamination can typically create a chemical reaction that would affect the fabric physical properties. Occurrences are fairly rare to our knowledge or could be mistaken for hydrolysis. Consequences of fabric damage are again depending on the resulting leakage or loss of mechanical properties.

Understanding and quantifying the chemical phenomenons behind the above age-related failures would be part of the proposed future study task.

3.3.3 Tears

Tears are more a consequence of the above failures modes than the cause of the failure itself. A tear can initiate and propagate under the pressure build up or deployment dynamic load but can only be the result of unusual deployment conditions or a fabric weakness (due to aging or foreign object).

Sometimes it is the combination of the above damages that make an inflatable beyond economical repair and lead to its replacement.

3.3.4 Floor fabric aging.

Possible ways of aging are mostly by peeling coating, delamination, tears, wear (typically if a slide is used for training and flying – which is the case at certain operators).
Immediate recommendation here that an in service slide should not be used for repetitive flight attendant training.

3.3.5 Aging of Girts

Girts by their location in the packed configuration near the door sill at the lower end of the pack and without protection from covers like the inflatable are exposed to the environment. This may result over time to aging of fabric (wear and humidity). Visual checks are covered in the CMM for possible replacement at the OEM. Some slides are fitted with quick replacement girts that can be replaced in the field.
Obviously the rupture of a girt could have serious consequences, as it ensures the evacuation system connection to the aircraft.

3.3.6 Radiant heat paint

This paint also has a tendency to age by flaking. But no reported failure are linked to this aspect. However an attempt could be made to correlate seam strength and paint degradation.

3.4 Study of practical cases

After reviewing the failure modes, let’s review some practical cases of failures reported in the field and analyze some scrapping data from Aérazur repair stations:

3.4.1 Failures reported from the field

We will review 3 cases that exhibit 3 different failure modes.
These examples only cover Air Cruisers / Aérazur products because this is the only incidents for which we have reliable report and investigation data.

3.4.1.1 Tear in a 20 year old A300 evacuation system (Europe)

In 1997, an Air Cruisers Company 20-year-old slide fitted on an A300 aircraft operated in Europe suffered a failure.

Apparently during a functional test deployment on aircraft, the system deployed normally and allowed the evacuation of 8 persons. However after 5 minutes a 2-meter long tear in the inflatable propagated along a center tube seam and rendered the system non-usable.

The last maintenance had been performed at Goodrich France the year before.

The investigation revealed that the inflatable fabric, sliding lane and girt fabrics exhibited signs of degradation due to aging. In particular the girt was worn, the sliding lane fabric delaminated and the report of fabric sticking suggests hydrolysis.

Definitive conclusions on the chain of events are not certain but the aging definitely appears to be the major cause of the failure.

This matter was brought up to the DGAC and resulted in a joint manufacturer / authority investigation.

3.4.1.2 Failed deployment due to cement deterioration
In 1998, an Air Cruisers Company 21-year-old slide fitted on an A300 aircraft operated in Europe failed to deploy. Note that the P/N is different from the above example.

The report is that the slide failed to deploy during an operational check on aircraft. There were several attempts, the slide remained packed into the door.

Shop investigation revealed that the pack release lanyard that will initiate the deployment sequence when pulled on never came into tension because the patch that connected it to the girt disbonded.

The cement deterioration over time lead to the chemical bond braking. The main cause of the failure again is aging.

3.4.1.3 Accelerated aging in a humid environment
Around 1998, an operator in the Indian subcontinent retrofitted 90 Aérazur manufactured evacuation systems fitted on A320 aircraft following a series of scheduled deployment incidents. Several slides failed around 10-12 years during deployment tests on aircraft.
Investigation at the Air Cruisers and involving cement experts revealed that the cement properties were deteriorated due to accelerated aging that compromised seam integrity. The inflatable leakage was not always important.

Cement deterioration is hydrolysis due to the extreme tropical environment that the systems continuously saw flying in the area.

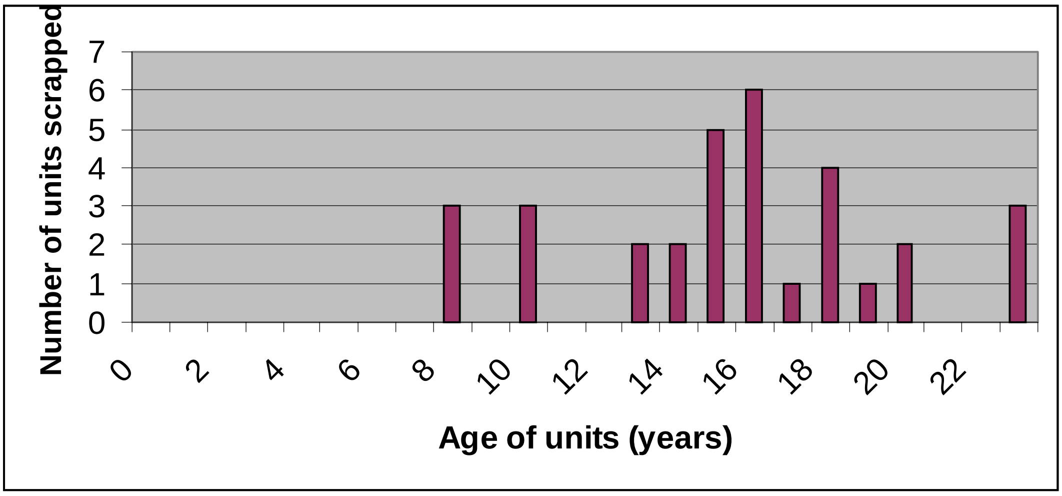
Maintenance practices influence are debated but it appeared clearly that for a long period the non air conditioned maintenance shop and storage lead to maintenance environment conditions outside of manufacturers recommendations.
It was acknowledged that for a long period the overpressure test was not performed or without manometer which prevented the detection of the seam properties weakening. Proper maintenance practices would have allowed to declare these units as not airworthy before they were mounted on aircraft and experienced a failure. It is not possible for the slide manufacturer to know the full maintenance history and practices seen by the failed units.

The issue is now closed as units subject to failure have been replaced and maintenance standard have been improved in cooperation with the evacuation system manufacturer.

Continuous study is performed by Air Cruisers on cement properties, but again tests in place if performed properly address the issue.

3.4.2 Repair station scrapping data

Find below a summary of some scrapping data for the A300/A310 Aérazur/Air Cruisers evacuation systems. This data was compiled from scrapping report of the Aérazur service centers in France in the 1995-1999 period.



This data gives an idea of slide aging. However it does not constitute sufficient data for analysis.

Clearly, units that were scrapped first are mostly from tropical, humid monsoon affected countries whereas the others appear to be from Europe or Mediterranean countries. However this sampling method shows some limits:

- the sample is limited (32 units)
- represents two aircraft types and 8 different P/N
- cause of scrapping is aging but precise analysis of aging is not available
- sample reflects more the customer base of the repair center than the worldwide fleet
- the age of scrapping does not indicate that the unit should not have been scrapped before (last maintenance at third party possible)

As developed later in this study, more reliable data could be obtained by a more systematic approach focusing on:

- the sampling quality (to limit aging factors interaction)
- quantifying aging and inflatable residual properties
- using some units from the field before they require scrapping

3.5 Maintenance issues

We covered maintenance issues in a practical example above. Here we would like to quickly review the question of training and packing as well control of non-OEM repair station and the reliability risk they represent.

3.5.1 Maintenance practices including packing

There is a possibility that the evacuation system is badly maintained or packed. Maintenance tasks described in the CMM are simple and easy to implement. Unworthy conditions, repair limitations are clearly spelled out. Proper observance of the recommendations is an issue beyond the manufacturer control. Obviously non respect of overhaul practices may lead to reliability issues.

Another possibility of reliability issues is packing of the evacuation system. The packing is basically a compacting process. You have to fit a certain quantity of equipment into a certain volume in a specific way. Manufacturers of evacuation systems issue folding procedure in appendix of the CMM explaining how to proceed. If the instructions are not respected there could be reliability consequences for example by:

- crushing necessary elements like the aspirators and therefore affecting their function,
- damaging inflatable fabric, leading to leaks
- or by misrouting a hose that could prevent proper deployment and render the system unusable.

During packing both the inflatable and rigid components of the system (such as reservoir, aspirator, packboard, cables, lamp harness, survival kit, Emergency Locator Transmitter) are compressed to fit in the volume allocated on the aircraft. Some packs may be of very high density and require significant expertise. Recurrent training seems to be the most appropriate way to ensure that the proper level of technical expertise is acquired and maintained. Aérazur and Air Cruisers Company offer, at their facility, packing training to operators at no charge.

We brought this item up in this study, because we reach here a different aspect of aging. As the equipment is in service for long period of time, maintenance shop may have capability and expertise issue when there is a high employee turnover. Another similar issue is that small shop may see a low volume of evacuation maintenance and therefore workers are sometimes detached to or from other workshop which may not be an ideal situation. Basically retaining the necessary knowledge is an aspect the reader may want to consider. Local airworthiness authorities probably may audit evacuation shops in a different way than an OEM which makes punctual courtesy or assistance visits to some operators.

Evacuation systems being a “go” “–no go” item, it is understandable that operators want to maintain their in-house capability. Other factors such as custom issues, employment policy and relatively high labor cost in the USA and France compared to developing countries all justify maintenance of evacuation systems by users or third party shops. As long as the standard of work is good we feel this is in the interest of the industry.

OEMs have in production deployment programs that may allow to detect deviation from proper packing in house and benefits from regular experience due to continuing production. This may not be the case in the field.

Floor run functional tests in our maintenance centers, may diagnose issues but make feedback to operator regarding previous maintenance practices more difficult and can only detect an issues 3 years after (based on maintenance periodicity) a possible issue was introduced or nor detected.

3.5.2 Major repairs

CMM defines that certain repair should not be attempted and units returned to the manufacturer. It appears essential also that components specific to the product and developed by the manufacturers and benefiting from their long experience, supplier base and expertise, be OEM supplied.

This is the case of the inflatable. Sometimes evacuations systems inflatables are replaced in maintenance but the rest of the system is salvaged and put back in service with a new inflatable. It may be following aging but also inadvertent deployment issues or damage due to other causes. Aérazur/Air Cruisers and we believe Goodrich feel that the replacement inflatable should be manufactured by the OEM.

There is the case of a Californian company which has apparently tried to copy evacuations systems inflatable using “major repair” process and got a local FAA approval for it. Some reports show that a new inflatable is produced and the original identification placard with the OEM name fitted. We do not have access to the complete file but there is reliability and traceability concerns.

Is this company manufacturing process able to provide the same technical level as that of the OEM? Is the resulting product in accordance with the CMM maintenance practice? Lastly, is reliability affected? It seems a valid concern from the OEM as ultimately the inflatable could be fitted in a system with its name. Obviously this issue is directly linked to aging systems which are subject to inflatable replacement.

3.6 Additional Reports (NTSB)

A recent NTSB study (NTSB SS-00/01) studied aircraft emergency evacuations. The NTSB also issued safety recommendations regarding evacuations (A-00-72 through 91 & A-99-99 through A-99-103). After review of some of the documents available, found in Appendix H, major findings related to evacuation system failures are given below. This review gives additional industry information on evacuation system in-service reliability.

- First of all it should be noted that there is no direct reference made to age of the evacuation systems as a cause of failure. Ages of systems concerned are not given.

- Reports say that the emergency lighting worked in all 30 cases studied in detail. This indicates that the aging study does not need to focus on lighting as a critical item when it comes to aging.

- In 43 of 46 evacuation cases, floor level exits were opened without difficulty. This concerns the door but also the evacuation system as there is an interface between the two and a possibility of door jamming affecting the slide function.

- Studies reveal issues with overwing exits operations. Not all overwing exits have slides. In addition the issues are with hatch handling and not slide related. Study has not identified slide function or aging issues at the overwing exits.

- An evacuation system has an issue in 37 percent of the evacuations studied in which their use was attempted. This may be seen as high but looking more in detail (see below) aging is rarely mentioned (only a damaged packboard with no age reference). In addition it should be kept in mind that an aircraft is certified for evacuation in 90 seconds using only half the exits. Despite that, obviously maximum reliability is the OEM goal.

- The best proof that the consequence of this statistical 37% figure are minimal is the following paragraph/statement:

"The majority of serious evacuation-related injuries in the Safety Board's study cases, excluding the Little Rock, Arkansas, accident, occurred at airplane door and overwing exits without slides."

- Review of evacuations involving slide failures sometimes show door issues such as with the power assist. Sometimes also an Airworthiness Directory existed on the product and was not incorporated yet or the issues was already identified (Boeing slide container). This brings up another industry concern for continued airworthiness which is S.B; implementation. There is also a wind condition that required one person to maintain the slide in position. Another slide issue is due to a flight attendant error. There is another identified technical issue with a DC-9 tailcone release handle. On a B767 there is an evacuation system compartment installation error, issue identified AD & SB issued. An MD83 aft galley exit failed to automatically inflate (but inflated manually) due to slide rigging / installation issue, Douglas AMM was amended to clarify installation. A B737 slide malfunction is possibly due to original girt design. This is somewhat an aging issue as nylon webbing reinforcement shrinkage (over time) is suspected as a cause for failure (door opening issues), AD 85-25-04 is now in place. On L1011, one slide does not deploy due to door problem, another door did not open due to packboard damage (no more details). On a DC10, one identified failure goes to improper function of regulator valve, another failure is due to an unconnected inflation cable.

- Revision of operators maintenance program for evacuation system is clearly raised. See A-99-100 & A-99-101. This clearly points meet concern expressed above about maintenance practices and major repairs.

- The NTSB recommends to the FAA a 10 percent deployment sampling plan (per aircraft type per fleet) and analysis of this data with parties involve including slide manufacturer. This could be very useful to detect issues before incidents arise. Aérazur / Air Cruisers feel video recording of these deployments is a must in order to conduct investigation and benefit from the experience of possible failures.

  The NTSB comments that the requirement for such scheduled deployment depends also on the aircraft manufacturer recommendation, the operator and the agreements reached with its national airworthiness authorities regarding the maintenance program. For example recommendations are included in the A320 Maintenance Planning Document (MPD). Examples of authority imposed deployment programs are with the CAA in December 1999 with Flying Colours and Caledonian (now merged as JMC Airlines) which allowed to detect 12 failures all of which have been diagnosed with video recording. The NTSB comments than American has an agreement with the FAA to perform an operational check of 4 out of 280 A300 slides or slide raft per year which may include inadvertent and actual evacuation deployments.

- The FAA responded to the NTSB safety recommendation A-99-100 by saying that the occurrence reporting system in place will allow to collect data that will allow to determine actions to address the NTSB concerns.

  The FAA says “a preliminary analysis of these data has identified at least six issues requiring resolution. These issues involve evacuation system design, **age-related concerns**, evacuation system certification basis, scheduled maintenance, and slide/raft packing and installation. These issues are further divided into maintenance manual procedures and personnel training/qualification issues. These issues will be addressed by the FAA/industry task group.”

  Following the FAA response the NTSB reiterates its safety recommendations A-99-100 and A-99-101 and will monitor the FAA progress on the identified issues related to slide reliability.

  Aérazur/Air Cruisers will obviously cooperate to the above. There is no specific information today as what age-related concerns are.

- For information, the study also comments that once a decision to evacuate is made, the crews must decide which exits to use in evacuating the airplane. In an ideal situation, all exits would be used to get passengers off the airplane as quickly as possible; however this ideal case is rarely achieved because exits are blocked by hazards such as fire or smoke. Airline procedures also impact that when no immediate danger (selection of safer exits).

4- Proposed Aging Research Study

4.1 Introduction

After presenting technological and regulatory background as well as aging information, this study has for objective to present to the JAA research comity a future and more detailed study on in service evacuation systems aging characteristics. The structure of such a study, based on the elements presented above, follows.

We would also like to outline an additional fact to consider when reviewing this future study: aircraft delivery happens by batch at many operators. Therefore there are probably cases in the field of aircraft/fleets equipped with aging slides at all emergency exits on most aircraft.

4.2 Goal of further research

The goal of the future study is to understand and quantify the mechanical properties and chemical phenomenons behind the inflatable aging aspects reviewed above. In-house laboratory tests on in-service, scrapped and new samples would be used.

This would allow to:

- understand aging of fabric and seams (in particular quantify hydrolysis and loss of mechanical properties vs. environment heat and humidity)
- define or adjust maintenance practices and their limits (and allow the authorities to see if they want to consider a possible life limit on evacuation systems)
- possibly establish aging curves per material type and/or environment

4.3 Test Program

4.3.1 Sampling

Laboratory accelerated aging tests have value but it is difficult to correlate them with in-service experience. For example laboratory aging conditions are not really representative of what a complete packed unit sees including maintenance, aircraft cycles, environment changes, aircraft configuration (door type and protection from the environment).

On the other hand, it is difficult to have a large sample of in-service serviceable units from operators to test as they must be bought back or exchanged. In addition, it is difficult to get the full history of the unit and therefore aging characteristics results could be influenced by other factors (maintenance practices, non reported incident…).

The intent of the research program is to conduct aging tests on both laboratory and in-service aged evacuation systems.

Sampling is quite simple for laboratory accelerated aging. A certain number of seams or fabric panels will be manufactured and tested.

Sampling of in-service seams and fabric is slightly more delicate. The goal is for a given P/N (several P/N should be studied) and a given geographical origin (tropical and non tropical environment) to have systems of different age (for example 6, 9, 12, 15, 18 years) to test.

All material studied will have to be returned with its full traceability and history.

Even though Aérazur and Air Cruisers have a significant share of the evacuation systems in service; it would be beneficial to test units from the other main slide manufacturer Goodrich to reflect a full picture of what is happening industrywide.

Evacuation system manufacturers can determine the maximum age reached by various types of evacuations systems seen in their repair stations: scrapping data. But this does not always guarantee that the unit should not have been scrapped before. In addition, it is impossible today for the OEM to determine the age of the entire fleet of evacuation systems in service. An estimate could be obtained by approaching airlines which should have the status of their evacuation system fleet in digital format.

Cooperation with airlines is needed to get units from service. If such a study is performed solely under an evacuation system manufacturer responsibility it may be difficult to get airline support. The airline may fear that as a result of such a study, part of the equipment in their fleet may be retired from service. There may be obvious concern that without a regulatory involvement such retirement may affect only airlines participating to the test and therefore penalizing them compared to non-participating airlines. An agreement has got to be worked out prior to testing.

A buy back program, authorities involvement and a large sample with identical test procedures may be a way of addressing the above concerns.

4.3.2 Proposed Tests

Each in service unit will be tracked along the test process to record:
- system traceability and history
- photos of system and possible defects
- sketches showing any specific defect

The destructive test program for a given system would have the following steps:
- Incoming inspection (condition of equipment)
- Cutting of several fabric and seam sample
- Testing of fabric samples (warp and fill): traction, tearing
- Testing of seams samples: pealing, shear test, chemical condition

All tests will be performed to existing standards when available.

Results of these tests will try to quantify for various environments what duration results in hydrolysis, seam failure, porosity or delamination.

The measurements of mechanical properties obtained with in-service units will be compared with:

- TSO requirements
- new system performances under similar test conditions
- and accelerated aging tests under similar test conditions

4.3.3 Additional areas of research:

Concerns about slide reliability and continuing airworthiness could also be addressed by cooperating with chosen airlines to get reliability data and by establishing a scheduled deployment program with video recording focusing on older systems. Implementation of S.B.s on older equipment and the consequences on reliability could be analyzed as part of that cooperation program.

An extension of the seam study could be to evaluate if there is a correlation between seam reflection paint condition (flaking) and the seam mechanical properties. The proper testing method has to be investigated. Depending on the findings and method used an OEM or field test could be worked out to assess the seam properties during maintenance, an investigation or a major repair.

Presence of micro-organism could also be looked for and possibly correlated with humidity and heat degradation of fabric and seams.

4.3.4 Proposed work

Here is a chronological summary of the proposed work for the future study:

- Establishment of a cooperation program with operators and possibly authorities to collect a representative sample of in-service equipment

- Incoming Inspection of in-service equipment

- Testing of in-service equipment

- New and accelerated aging testing

- Test report and technical recommendations

CONCLUSIONS

This study presented evacuation systems and the related regulations. Then failures modes were presented focusing on the inflatable. Major age-related failure modes identified are porosity, hydrolysis, fabric delamination and seam failure which can render a slide or slide/raft unusable in case of emergency evacuation. Scrapping data and experience show that fabric and seam aging is related to the environment, maintenance practices and the protection the aircraft installation provides.

Even though there is an industry consensus on maintenance recommendations, we feel the practical cases and industry reports show that the aging process needs to be further quantified to possibly adjust industry recommendations and limitations.

Therefore a future research program is presented. By performing destructive testing on fabric and seam samples from both in-service units and laboratory accelerated aging samples, aging characteristics, according to the climatic environment, and aircraft installation, could be examined and compared with these of new equipment. Aging curves could possibly be established. The required cooperation with airlines could be extended, for a given period, to a reliability program including evacuation system deployment plan recorded on video.

Continuing airworthiness of evacuation systems encompass many aspects such as its door integration, deployment procedures, proper maintenance and packing. Aging of the inflatable is one of them and we believe the proposed study can benefit the entire industry and maintain if not improve safety levels in case of emergency evacuations.

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