The use of computer simulation for aircraft evacuation certification: A report from the VERRES project

E.R.Galea
Fire Safety Engineering Group
University of Greenwich,
London SE10 9LS, UK
http://fseg.gre.ac.uk/

ABSTRACT

In this paper a methodology for the application of computer simulation to the evacuation certification of aircraft is suggested. The methodology suggested here involves the use of computer simulation, historic certification data, component testing and full-scale certification trials. The proposed methodology sets out a protocol for how computer simulation should be undertaken in a certification environment and draws on experience from both the marine and building industries. Along with the suggested protocol, a phased introduction of computer models to certification is suggested. Given the sceptical nature of the aviation community regarding any certification methodology change in general, this would involve as a first step the use of computer simulation in conjunction with full-scale testing. The computer model would be used to reproduce a probability distribution of likely aircraft performance under current certification conditions and in addition, several other more challenging scenarios could be developed. The combination of full-scale trial, computer simulation (and if necessary component testing) would provide better insight into the actual performance capabilities of the aircraft by generating a performance probability distribution or performance envelope rather than a single datum. Once further confidence in the technique is established, the second step would only involve computer simulation and component testing. This would only be contemplated after sufficient experience and confidence in the use of computer models have been developed. The third step in the adoption of computer simulation for certification would involve the introduction of several scenarios based on for example exit availability instructed by accident analysis. The final step would be the introduction of more realistic accident scenarios into the certification process. This would require the continued development of aircraft evacuation modelling technology to include additional behavioural features common in real accident scenarios.

1. INTRODUCTION

This paper reports on research work undertaken for the European Commission funded study GMA2/2000/32039 Very Large Transport Aircraft (VLTA) Emergency Requirements Research Evacuation Study (VERRES). The VERRES consortium was made up of University of Greenwich, Cranfield University, The UK CAA, EADS Airbus, Virgin Atlantic and Sofreavia with ETF (SNPNC) and the JAA as observers. The purpose of VERRES was to investigate a number of issues relating to post-accident survivability of future large aircraft. A particular focus was on evacuation issues with detailed investigation of the role of computer models. This paper addresses the research undertaken for Work Package 2 and suggests a methodology for the application of computer simulation to the certification of aircraft. While the approach is intended to address the requirements of VLTA, it is applicable to all aircraft types. The full report can be found on the FSEG web pages at: http://fseg.gre.ac.uk/fire/VERRES_Project.html.

2. CURRENT EVACUATION CERTIFICATION PRACTICE

Before embarking on this discussion it is useful to review the current regulatory process. Regulators attempt to enforce and maintain safety standards through a set of essentially prescriptive rules that have evolved over time. In Europe they are know as Joint Aviation Requirements (JAR) [4] while in the USA the rules are known as the Federal Aviation Regulations (FAR) [3]. An example of one of the rules that has evolved over time relating to aircraft evacuation efficiency is the so-called “60-foot” rule. The rule appears in the FAR (i.e. 25.803 (f) (4)) [3], and there is an equivalent ruling in the JAR. The JAR rule states;

“For an airplane that is required to have more than one passenger emergency exit for each side of the fuselage, no passenger emergency exit shall be more than 60 feet from any adjacent passenger emergency exit on the same side of the same deck of the fuselage, as measured parallel to the airplane’s longitudinal axis between the nearest exit edges.”[3,4]

These prescriptive regulations specify design rules that must be followed in the design of all commercial passenger aircraft carrying more than 44 passengers. Compliance with these rules can easily be visually checked by inspectors both during design – by viewing aircraft scale drawings - and when the first aircraft rolls off the production line. In addition to these prescriptive rules is a performance based requirement commonly known as the *‘90 second certification test’* [5]. Compliance with this rule is demonstrated by performing a full-scale evacuation demonstration. The demonstration is performed with a representative cross-section of the travelling public (age and gender distribution), in darkness and utilising only half of the normally available exits. Crew and passengers do not know before hand which exits will be made available. The test involves evacuating all passengers and crew to the ground (using slides if they are fitted) within 90 seconds if the aircraft is to pass the performance test. A complete video record is made of the event including behaviour within the cabin and at the exits. The video recordings of the evacuations are a valuable source of data on the performance level achieved during these types of certification evacuations. The certification performance test is only intended to provide a measure of the performance of the aircraft under an artificial benchmark evacuation scenario. It is not intended to predict the performance of the aircraft under a realistic accident scenario. However, it allows the performance of different aircraft to be compared under a set of identical – if somewhat artificial – scenario conditions.

There are several difficulties with the current 90 second trial. There is considerable threat of injury to trial participants. Between 1972 and 1991 a total of 378 volunteers (or 6% of participants) sustained injuries ranging from cuts and bruises to broken bones [6]. In October 1991 during the McDonnell Douglas evacuation certification trial for the MD-11, a female volunteer sustained injuries leading to permanent paralysis. Another difficulty is the lack of realism inherent in the 90-second evacuation scenario. Volunteers are subject neither to trauma nor to the physical ramifications of a real emergency situation such as smoke, fire and debris, the certification trial provides little useful information regarding the suitability of the cabin layout and design or the cabin crew procedures in the event of a real emergency. The Manchester disaster of 1985, in which 55 people lost their lives, serves as a tragic example. The last passenger to escape from the burning B737 aircraft emerged 5.5 minutes after the aircraft had ceased moving, while 15 years earlier in a UK certification trial, the entire load of passengers and crew evacuated the aircraft in 75 seconds [7,8]. In the certification trial, while passengers are keen to exit as quickly as possible, the behaviour exhibited is essentially co-operative, whereas in real accident situations the behaviour may become competitive. Even if complex issues of fire etc are excluded from consideration, relatively simple issues such as exit selection are far from realistic. Providing all exits on one side of the aircraft bears little or no resemblance to realistic accident scenarios.

On a practical level, as only a single evacuation trial is necessary for certification requirements, there can be limited confidence that the test - whether successful or not - truly represents the evacuation capability of the aircraft. In addition, from a design point of view, a single test does not provide sufficient information to arrange the cabin layout for optimal evacuation efficiency, and does not even necessarily match the types of configuration flown by all the potential carriers.

Finally, each full-scale evacuation demonstration can be extremely expensive. For instance an evacuation trial from a wide-body aircraft costs in the vicinity of $US2 million [6]. While the cost may be small in comparison to development costs, it remains a sizeable quantity.

A primary driver for the development of aircraft evacuation models is to augment and eventually replace the current certification process. In this application the model is intended to simply replicate the live certification trial and if possible to address the identified problems and shortcomings of the certification process. Several models (e.g. airEXODUS, GPSS [1]) have been developed to address these needs. It is worth noting that evacuation models designed to address 90-second certification applications have access to a plethora of data, in the form of video footage of previous 90-second certification trials, upon which behaviours within the model can be derived and key model parameters set.

Evacuation modelling for accident reconstruction is considerably more demanding than certification modelling. Some models have been developed in an attempt to simulate real emergency evacuation scenarios (e.g. airEXODUS, ARCEVAC, GOURARY, DEM, MACEY see [1] for details). An air accident as defined within JAR and FAR is:

> *"An occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, where any person suffers death or serious injury, or the aircraft received substantial damage."* [9].

Modelling real (incident or accident) emergency evacuation is far more complex than certification modelling for a number of reasons. Firstly, intrinsic variability in real emergencies leads to a myriad of different possible evacuation scenarios. For example, whereas in one emergency evacuation the aircraft fuselage may expose the cabin interior to a life threatening fire [10], in another, the cabin may remain intact but passengers may be subjected to a mild threat of smoke [11]. The aircraft could be on its landing gear in one scenario [12] but may have partial failure in another [11]; the aircraft may be partially immersed in water as in the case of a runway overrun [13], etc. Thus the range of human behaviour that needs to be modelled is far more extensive than that found in the certification scenario.

Furthermore, reliable data on human behaviour and performance under these realistic accident scenarios is more difficult to obtain. There are fewer sources of accurate quantitative information on human performance in emergency evacuation situations. Unlike, 90-second certification trials there are no video recordings of the unfolding evacuation upon which behaviour can be identified and model parameters set. As such information regarding the evacuation is limited to the testimonies of surviving passengers, crew, and rescue workers and data from contrived experimental trials.

3. THE USE OF EVACUATION MODELS FOR CERTIFICATION APPLICATIONS

Before computer models can reliably be used for certification applications they must undergo a range of validation demonstrations. While validation will never prove a model correct, confidence in the models predictive capabilities will be improved the more often it is shown to produce reliable predictions.

The success of at least some aircraft evacuation models (e.g. airEXODUS in [1,27,28,29,30,33]) in predicting the outcome of previous 90-second certification trials are compelling arguments of the suitability of these models for evacuation certification applications - at least for derivative aircraft. For aircraft involving truly ‘new’ features it is expected that evacuation models in conjunction with component testing of the new feature will be necessary. Examples of new features include a new exit Type or an established exit configuration placed at a sill height surpassing that previously used. In both these examples it is assumed that sufficient data does not exist that would allow a reliable representation within the evacuation model. In these cases, the combination of computer model and component testing offers a sensible and reliable alternative to full-scale live evacuation trials.

However, it is not sufficient to simply replace full-scale testing of aircraft with a combination of computer modelling and component testing. While this may make testing the aircraft a safer and more efficient process, computer modelling should also improve the certification process i.e. provide the aviation community and the passengers that use the aircraft something more than the simple one-off testing provides. If we are to rise to this challenge it is essential that we begin to question some of our current preconceptions concerning certification.

3.1. What constituents a certification scenario?

When examining the possible use of aircraft evacuation models for certification purposes, we must first establish what will be the nature of the certification scenario. An aircraft evacuation scenario – be it real accident, computer generated or live full-scale experiment - is made up of the following six key components:

- ***Aircraft configuration specification:*** consisting of cabin layout, exit configuration and exit availability.
- ***Aircraft environmental specification:*** consisting of the orientation of the aircraft and the nature of the cabin atmosphere with regard to heat, smoke and toxic gases.
- ***Crew behaviour:*** consisting of the number and role of cabin crew, level of assertiveness displayed by the crew at exits and the exit ready times.
- ***Passenger population distribution:*** consisting of the nature of the evacuating population, either a standard 90 second population or other mix of passengers including for example injured/disabled passengers.
- ***Passenger behaviour:*** consisting of standard 90 second type non-competitive behaviour or accident specific competitive behaviour (e.g. seat jumping, aisle swapping, etc).

- ***Passenger exit selection:*** consisting of which exits the passengers will attempt to utilise during the evacuation, this can be categorised into essentially one of three basic types, optimal exit, nearest exit, or case specific sub-optimal exit selection.

Changing the selection of any of these parameters will change the outcome of the evacuation. In effect, changing these parameters is equivalent to changing the nature of the question that is being posed. Computer simulations used to represent current 90 second certification scenarios would typically consist of the following settings:

- ***Aircraft configuration specification:*** cabin layout and exit specification given by aircraft drawings exit availability determined by standard 90 second protocol.

- ***Aircraft environmental specification:*** normal orientation, darkness/emergency lighting and no fire products.

- ***Crew behaviour:*** assertive crew and generalised exit ready times.

- ***Passenger population distribution:*** standard 90 second population distribution.

- ***Passenger behaviour:*** standard 90 second type non-competitive behaviour.

- ***Passenger exit selection:*** optimal exit selection.

Evacuation models have the capability of examining many different types of evacuation scenario. What scenario should be considered for certification by computer model? Should the current certification scenario be maintained or should a range of scenarios be considered? Perhaps a selection of the most likely evacuation scenarios should be considered or simply the most severe likely evacuation scenario? The selection of suitable evacuation scenarios could be guided through analysis of past accident data – from for example one of the several accident databases that have been developed [17,18,34,35]. For example, the analysis of past accidents can suggest which exit combination is most likely to occur. This could be used to assist in selecting the number and location of exits to assess in the certification trial. In addition, it is suggested that consideration of likely failure modes should also be considered. In addition to simulating the "optimal" scenario it is important to simulate likely "what if" scenarios that may occur. These are likely to be aircraft specific and depend on the nature of the aircraft geometry.

Furthermore, unlike full-scale testing, evacuation models allow the possibility of performing many repeat simulations for any particular scenario thereby producing a range of results for any given scenario or collection of scenarios. Indeed, it may even be argued that rather than simply testing a single interior layout configuration, each layout flown by a carrier should be tested by computer simulation. In this way evacuation simulation provides better insight to the performance capability of the aircraft under a range of scenarios.

3.2. Acceptance Criteria

Regardless of the accident scenario selected for certification testing, how do we determine that an aircraft has met the pass/fail criteria, how do we establish the "deemed to satisfy" requirement? For a particular scenario should the requirement stipulate that ***every*** simulation be sub-90 seconds? Or should the distribution mean or the 95 percentile result be sub-90 seconds? In the hypothetical example provided (see Figure 1), 950 of the 1000 simulations (i.e. 95%) produced an evacuation time less than 90 seconds. Should this aircraft configuration be deemed to pass or fail the certification criteria?

An interesting example of this dilemma was shown in a recent report to the UK CAA [29] concerning the validation of the airEXODUS model. In this example, the aircraft achieved an actual certification performance of 83.7 seconds with a mean airEXODUS predicted evacuation time of 82.7 seconds. While these times represent the out of aircraft time for the passengers, the actual certification on-ground time for the passengers and crew was such that the aircraft clearly passed the certification requirement. However, of the 1000 simulations performed using airEXODUS for this aircraft, three or 0.3% are predicted to marginally fail the certification requirement. If the mean rule (i.e. 50% less than 90 seconds) or the 95% rule were adopted the aircraft would clearly satisfy these requirements and be considered acceptable. However, if the 100% requirement were adopted the aircraft would not be considered acceptable. As this aircraft is considered to be acceptable (on the basis of the single actual certification trial result) perhaps the deemed to satisfy limit should be placed at 0.3%? If this general approach were considered viable, the logical extension would require that all of the past aircraft that have undergone the certification process would need to be assessed using computer simulation and a suitable acceptance level derived from this analysis.

Any aircraft configuration will produce a range of evacuation times over a number of tests, some of which may well be over the certification maximum of 90 seconds. Under the current 'make or break' single test regime, a single performance result is selected from this 'unknown' distribution of possible evacuation times and put forward as the certification performance. The aircraft will pass as long as the result is below the 90 second threshold. It is impossible to know whether or not the outcome is a fair reflection of the aircraft's evacuation capability. In contrast, the multiple tests enabled by computer simulation generate a distribution of times, reflecting what would happen if the full-scale evacuation could be repeated. This provides a better indication of the performance capability of the aircraft.

It has been argued by some that to achieve parity with the current certification process, 100% of the generated simulations should produce times less than 90 seconds to pass. Clearly, this would not achieve parity with the current certification process. For those who wish to achieve some form of parity with the current certification process, an alternative approach may be to generate only a single evacuation time from the modelling analysis. As part of this methodology it would still be necessary to first generate the evacuation time distribution using many repeat simulations. This would generate the probability space of possible evacuation times for the aircraft configuration under the selected certification scenario. From this probability distribution a single evacuation time would be selected at random and deemed to be the certification performance of the aircraft. This in essence is equivalent to the current practice of performing only a single trial for certification. Using this approach the same acceptance criteria could be applied to the numerically generated certification time as that applied to the full-scale trial generated certification time. In this way, the modelling process would replicate the current certification process where only a single evacuation time is put forward and so provides a means to circumvent the need to re-define acceptable performance.

However, a significant downside of this methodology is that a considerable amount of potentially useful information regarding the performance of the aircraft is disregarded. Rather than attempting to achieve parity with the current standard the industry should be endeavouring to produce a more meaningful measure of aircraft evacuation performance.

This raises the question, does the "magic number" 90 seconds have any actual meaning under these circumstances?

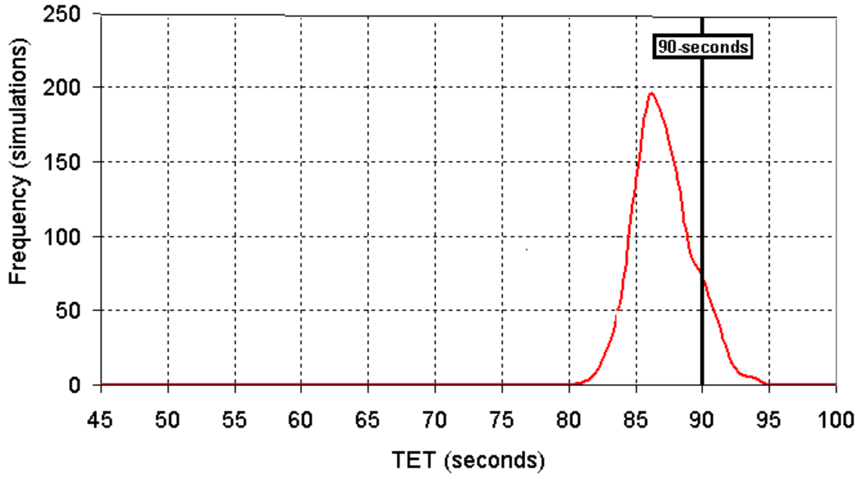

Figure 1: Numerically generated evacuation time distribution (frequency Vs evacuation time) for a particular scenario for a hypothetical aircraft configuration.

3.3. Experience from other industrial sectors

Internationally, throughout the building industry, similar issues are being addressed through the replacement of the old prescriptive building requirements with performance based regulations. Prescriptive building regulations the world over suggest that if we follow a particular set of essentially configurational regulations concerning travel distances, number of exits, exit widths, etc it should be possible to evacuate a building within a pre-defined acceptable amount of time. In the U.K. for public buildings this turns out to be the "magic number" 2.5 minutes. Part of the risk analysis process involves the concept of the Available Safe Egress Time or ASET and Required Safe Egress Time or RSET. For a particular application the ASET may be based on the time required for the smoke layer to descend to head height while the RSET may be the time required for the occupants to vacate the structure. Put simply, the ASET must be greater than the RSET. The circumstances of the scenario under consideration dictate both the ASET and RSET and several scenarios may need to be examined before any conclusions can be reached. As part of this risk analysis process credible fire scenarios (including fire loads, fire evolution, fire size etc) are postulated along with credible evacuation scenarios (including number and type of people, occupant response characteristics, etc). Computer based evacuation and fire models are being used to assist in the determination of both the ASET and the RSET. In this way evacuation models are providing a means by which the complex interacting system of structure/environment/population can be assessed under challenging design scenarios.

Recently in the marine industry a half way house approach has been adopted. Rather than use the building industries ASET/RSET approach, IMO have adopted as draft guidelines a methodology where the ASET is set by a prescriptive limit, similar in concept to the 90 second "magic number" used in the aviation industry while the RSET can be determined by computer simulation [1,31]. To determine the RSET the submitted design is subjected to four benchmark scenarios each evaluated by computer simulation. The precise nature of the benchmark scenarios are prescribed in a similar way to the current 90 second certification trial. The ship design must pass all four benchmark scenarios in order to be deemed to satisfy the requirement. Furthermore, IMO have acknowledged that a distribution of evacuation times will be produced for any single evacuation scenario. As a result, they have adopted the 95% rule described above.

A similar methodological approach to either the building or maritime industries should be considered for aviation.

Other disciplines such as the building and maritime industries accept computer based simulations as part of the certification process. These have adopted a common approach to the validation and verification of evacuation models that could easily be adapted for aviation applications. Furthermore, in the marine industry, specific documentation is required to be submitted along with the simulation results. This documentation is intended to demonstrate the credibility and appropriateness of the approach adopted and furthermore allow easy verification and reproduction of the submitted results [1,31,32]. These requirements include the specification of:

- the variables used in the model to describe the dynamics, e.g. walking speed of each person;
- the functional relation between the parameters and the variables;
- the type of update used within the model;
- the representation of stairs, doors, … and other special geometrical elements and their influence on the variables during the simulation and the respective parameters quantifying this influence;
- a detailed user guide/manual specifying the nature of the model and its assumptions and guidelines for the correct use of the model and interpretation of results should be readily available.

Certification analysis performed for the aviation industry using computer simulation should require a similar level of documentation.

3.4. Suggested Certification Methodology

As in the marine and building industries, it is essential that a protocol be developed for the acceptable use of computer simulations for aircraft certification applications. However, it is essential to note that such a methodology is not intended to replace the entire certification process. Existing testing such as slide inflation testing, door opening times, etc would still be required as would compliance with prescriptive rules. The protocol is only intended as an alternative to the current full-scale evacuation demonstration.

Such a protocol should address the following five key issues:

(i) Model validation and demonstration requirements

Before a model is used for a certification application it must be demonstrated that the model is capable of simulating the certification test with a specified degree of accuracy. The cases examined in the recent report on the validation of the airEXODUS aircraft evacuation model [33] could form the basis of such validation/demonstration cases.

(ii) **Simulation protocols**

It is necessary to specify the manner in which the simulations are to be run and the nature of the core results must be presented. This should include for instance the number of repeat simulations required, the nature of the data used in the simulations, the nature of the population to be used, etc.

(iii) **The Scenarios to be Investigated**

The number and nature of the scenario(s) to be investigated must be specified. For example, a range of scenarios could be considered which includes the standard 90 second scenario as a base case and additional scenarios drawn from accident analysis as suggested in section 3.1. The scenario specification should specify the six key components as identified in section 3.1.

(iv) **The Acceptance Criteria**

Due to the probabilistic nature of the results produced from repeated simulations, it is essential that a rational acceptance criterion be developed. This should be based on meaningful statistical analysis as outlined in section 3.2.

(v) **Supporting Documentation.**

The evacuation analysis must be supported by appropriate documentary evidence. This should provide a thorough justification for the analysis presented – covering both the numerical technique and data used - and provide a means of reproducing the analysis in some way. The approach adopted by International Maritime Organisation discussed in section 3.3 provides the basis for developing such a system for aviation applications.

Until such protocols are in place, it is unlikely that the aviation industry will adopt the use of computer simulation for evacuation certification analysis. Hence it is essential that significant effort should be directed towards producing an acceptable framework for the application of aircraft evacuation models to the regulatory environment. The above is an outline of such a protocol.

3.5. Suggested use of models for certification

In suggesting the use of computer models for aircraft certification we must be mindful of the point made earlier that it is not sufficient to simply replace full-scale testing of aircraft with a combination of computer modelling and component testing. While this may make testing the aircraft a safer and more efficient process, computer modelling should also improve the certification process i.e. provide the aviation community and the passengers that use the aircraft something more than the simple one-off testing provides.

While a methodology for the use of computer simulation for certification applications has been suggested in section 3.4, the nature of the scenarios to be considered for certification has not been finalised. It has been suggested that through the use of computer simulation a range of evacuation scenarios should be examined for certification purposes. As a first step in the process of developing these scenarios it is suggested that the current 90 second certification scenario be adopted as the basis for the computer analysis.

The success of evacuation models such as airEXODUS in predicting the outcome of previous 90-second certification trials is a compelling argument of the suitability of this model for predicting evacuation performance under certification conditions - at least for derivative aircraft (for example see [27,28,29,30,33]). These applications would simply involve the computer simulation being used to perform the full-scale evacuation demonstration. This could only be achieved for situations in which reliable data is available on which to base the evacuation simulation. For aircraft involving truly 'new' features – in which data is not available - it is expected that evacuation models in conjunction with component testing of the new feature will be necessary. Examples of new features include a new exit Type or an established exit configuration placed at a sill height surpassing that previously used. In both these examples it is assumed that sufficient data does not exist that would allow a reliable representation within the evacuation model. In these cases, the combination of computer model and component testing offers a sensible and reliable alternative to full-scale live evacuation trials.

It has also been demonstrated through computer simulation that even though an aircraft may pass a single one-off certification trial, there may be a finite chance that the aircraft will fail to meet the requirements of the certification process if the trial were repeated a number of times [33]. This information is invaluable when attempting to assess the true evacuation performance of the aircraft. It provides insight into the design of the aircraft that can only be practically provided through evacuation simulation.

Thus, computer based aircraft evacuation simulation using the standard evacuation certification scenario has been shown to:

- be capable of reproducing the evacuation performance of aircraft, passengers and crew in full-scale certification trials,
- be a safer and more efficient process than full-scale evacuation trials,
- provide better insight into the actual performance capabilities of the aircraft by generating a performance probability distribution or performance envelope rather than a single datum, and
- be capable of easily and efficiently investigating a range of relevant certification scenarios rather than a single scenario.

These capabilities provide the aviation community (passengers, crew, manufacturers, airlines, regulators) with significantly more than the current simple one-off testing procedure provides and thus should be considered a useful alternative to full-scale testing. Thus as an alternative to full-scale testing, aircraft evacuation models could be used to simulate the performance of the aircraft using the current single certification scenario. The simulations would be run using the outlined methodology and would provide better insight into the actual performance capabilities of the aircraft by generating a performance probability distribution or performance envelope rather than a single datum. If suitable data were not available to perform reliable simulations, than component testing in conjunction with simulations would be necessary to satisfy the certification process. All other prescriptive rules and requirements would still apply, the evacuation simulation simply replacing the final full-scale demonstration. This approach should be considered the first step in the process of introducing computer simulation to aircraft evacuation certification. As confidence in the technique develops, additional, more representative and demanding scenarios could be added to the certification process.

While the above approach would appear to be a logical first step to the introduction of computer modelling to certification, it may be considered too radical by some sectors of the aviation industry that are still sceptical of the capabilities of evacuation models. An alternative strategy would be to gradually phase in the use of evacuation models, using computer models to address the recognised failings of the current evacuation certification process. This would involve evacuation models being used in conjunction with full-scale evacuation demonstrations. Such an approach would provide two major benefits; it would improve the current certification process while allowing further confidence to be established in the use of aircraft evacuation models.

In this alternative first step, the full-scale evacuation certification demonstration would be run in the usual manner. However, there would be an additional requirement to use computer simulation to perform repeated simulations of the certification trial conditions in order to produce a probability distribution of likely evacuation performance. Given that the computer model was set up to simulate the same situation as occurred in the actual full-scale trial, it would be expected that the data point from the full-scale certification trial would fall on the probability distribution produced by the computer simulation (see reference [33] for examples). The pass-fail criteria could then be based on both the actual result generated in the full-scale trial and the model predictions. This approach would provide a number of benefits, namely:

- provides further validation of the modelling process,
- provides insight into the performance of the aircraft under repeated trials,
- delivers improved confidence in the certification procedure.

As suggested previously, all the simulations would be run using the outlined methodology. If suitable data were not available to perform reliable simulations, than component testing in conjunction with simulations would be necessary to satisfy the certification process. All other prescriptive rules and requirements would still apply, for example slide inflation tests and door opening trials would still be required.

As a second step in the adoption of computer simulation for certification the full-scale trial could be dropped in circumstances where there was sufficient data on which to be confident in the modelling approach. This would only be contemplated after sufficient experience and confidence in the use of computer models had been developed.

The third step would then involve expanding the nature of the certification scenario and perhaps introducing several certification scenarios. The first scenario would be the standard 90 second certification scenario but in addition, several other simulated evacuation scenarios could be investigated. These could be based on data from accident investigation suggesting likely exit combinations (see section 3.1).

As a final step, the nature of the evacuation scenarios investigated in the certification process could be made more realistic, with the introduction of more credible accident scenarios. However, for this to become a reality, further effort must be directed towards the continued development of aircraft evacuation modelling technology to include additional behavioural features common in real accident scenarios. It is suggested that additional capabilities to explicitly represent the crew and their interactions with passengers should be developed. This should include the ability to simulate crew directed by-pass and re-direction. Wherever possible these developments should be guided by evidence available from actual accidents. Additional capabilities relating to behaviours noted in actual accidents such as the ability for passengers to jump over seats and switch aisles should also be developed and where possible this development should be guided by actual accident analysis. As suggested in [2], this work is already underway but will require additional support if it is to develop to the point where it can be reliably used for certification applications.

4. CONCLUSIONS

As part of VERRES Work Package 2, it has been suggested that evacuation models offer a possible alternative to the current practice of performing a single live evacuation demonstration. While the introduction of computer models for aircraft evacuation will potentially solve some of the existing difficulties and shortcomings posed by current certification testing, it will introduce new questions, pose new challenges and offer new opportunities that need to be addressed. However, by addressing these new challenges we may achieve our goal of producing safer aircraft.

One of these challenges concerns the existence and availability of data. In order to perform reliable simulations, evacuation models are reliant on data. The nature of the intended simulation will dictate the type and quantity of the required data, with accident reconstruction possessing the greatest challenges. For the simulation of the current certification scenario, much data already exists and has been analysed while much more data is available and yet to be analysed. However, more data is required and a concerted effort must be undertaken to collect and analyse the required data. This will require co-operation between manufacturers, regulatory authorities and research groups.

A second challenge concerns the development and adoption of a framework for the application of aircraft evacuation models to the regulatory environment. As in the marine and building industries, it is essential that a suggested protocol be developed for the acceptable use of computer simulations for aircraft certification applications. Until such protocols are in place, it is unlikely that the aviation industry will adopt the use of computer simulation for evacuation certification analysis. An outline of such a protocol has been suggested in this document.

Along with the suggested protocol, a phased introduction of computer models to certification has been suggested. Given the sceptical nature of some in the aviation community regarding the capabilities of computer simulation, this would involve as a first step the use of computer simulation in conjunction with full-scale testing. The computer model would be used to reproduce a probability distribution of likely aircraft performance under current certification conditions and in addition, several other more challenging scenarios could be developed. In these cases, the combination of full-scale trial, computer simulation (and if necessary component testing) would:

- provide better insight into the actual performance capabilities of the aircraft by generating a performance probability distribution or performance envelope rather than a single datum, and
- be capable of easily and efficiently investigating a range of relevant certification scenarios rather than a single scenario.

These capabilities provide the aviation community (passengers, crew, manufacturers, airlines, regulators) significantly more than the current simple one-off testing procedure provides. Once further confidence in the technique is established, the second step would only involve computer simulation and component testing. This would only be contemplated after sufficient experience and confidence in the use of computer models had been developed.

The third challenge involves the continued development of aircraft evacuation modelling technology to include additional behavioural features common in real accident scenarios. It is suggested that additional capabilities to explicitly represent the crew and their interactions with passengers should be developed. This should include the ability to simulate crew directed by-pass. Wherever possible these developments should be guided by evidence available from actual accidents. Additional capabilities relating to behaviours noted in actual accidents such as the ability for passengers to jump over seats and switch aisles should also be developed and where possible this development should be guided by actual accident analysis. With this development, the third step in the adoption of computer simulation for certification could be taken. This would involve the introduction of more realistic accident scenarios into the certification process.

Finally, the challenge facing all the stake holders involved in aircraft certification i.e. regulators, approval authorities, accident investigators, manufacturers, airlines, unions, and ultimately the travelling public, is to develop a better understanding of the modelling technology being developed and with that understanding specify relevant design protocols and standards. Here examples from both the building and maritime industries provide useful models upon which to base an aviation strategy. For this to have a proper perspective it is essential that all the stakeholders have a good appreciation of the current certification process and its limitations.

By adopting this approach we may achieve our goal of producing safer aircraft which the industry claim they desire and the travelling public certainly deserve.

5. REFERENCES

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