THE airEXODUS EVACUATION MODEL AND ITS APPLICATION TO AIRCRAFT SAFETY

By

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The tragedy of September 11

- Our hearts and thoughts are with the innocent victims and the family and friends they left behind.
- We honour the fire fighters and rescue workers who gave their lives.
- We salute their colleagues who continue to put themselves in harm's way.
- Let their sacrifice be our spur to make the world a safer place.

E Galea 18 September 2001

Acknowledgements

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- **The views expressed in this paper are solely those of the authors.**

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  - Performance based codes and the move to evacuation modelling.
  - Aircraft evacuation modelling and the need for data
- The airEXODUS Evacuation Model
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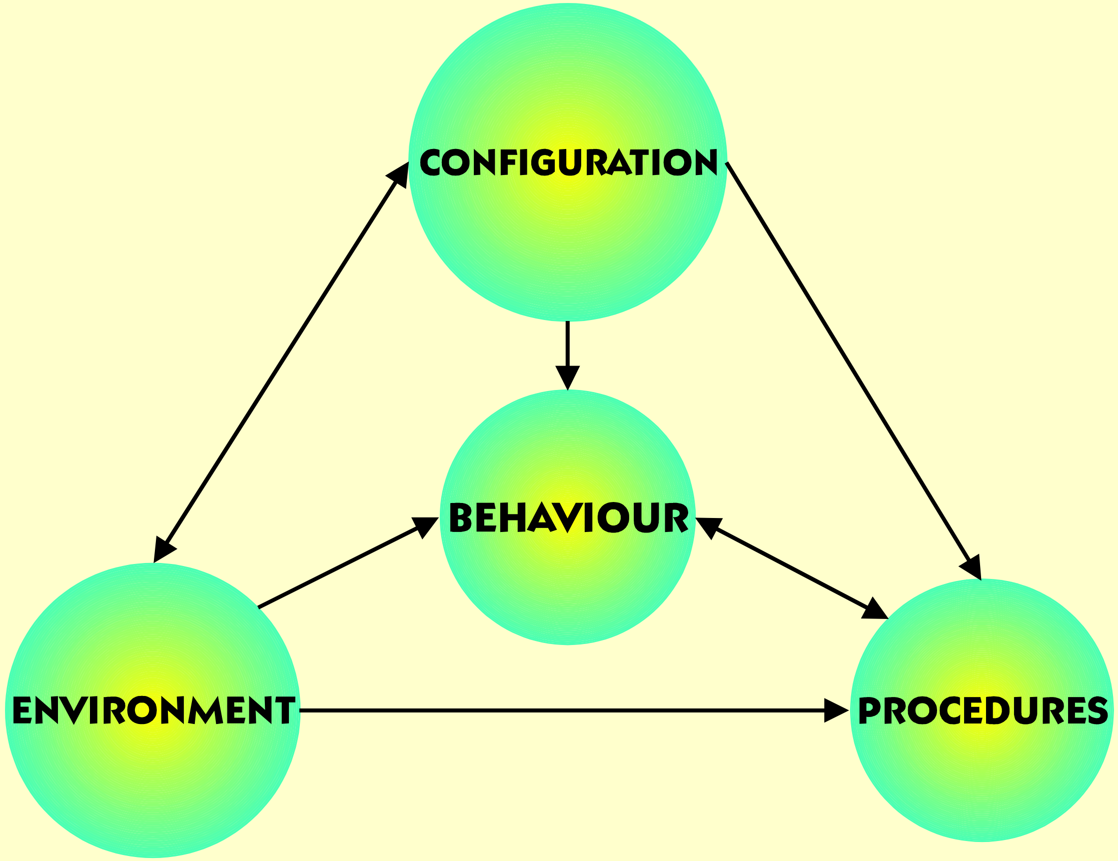
EVACUATION MODELLING

- In the design and modification of buildings, ships and aircraft, evacuation and fire safety related issues have traditionally been dealt with through **PRESCRIPTIVE CODES.**
  - Regulations established over time based on experience of past fires, usually incorporate many ***"magic numbers".***
- New paradigm in the building and maritime industries is the **PERFORMANCE CODE**
  - These specify objectives and performance levels rather than pre-determined solutions.
  - **Mathematical Models**, together with **reliable data**, provide a means of determining and examining the proposed designs.
  - These allow the engineer to select the most efficient design that meets the set objectives and delivers the required performance.

Aircraft Evacuation Models

- **As in the building and maritime industries, computer-based aircraft evacuation models have the potential to:**
  - produce safer more rigorous and rational certification criteria
  - assist in developing more efficient crew emergency procedures
  - optimise passenger movement, loading and disembarkation
- **These issues can be brought to the design phase**
- **Computer models can also be used as an aid in:**
  - cabin crew training
  - accident investigation

What needs to be modelled



Four main interacting aspects which control evacuation performance.

The Need For Data

- **Models require data: identify/quantify/validate**
- **What are the main sources of aviation Data?**
- Three Main Data Sources
  - aircraft accident reports
  - aircraft certification reports/videos
  - experiments, e.g. Cranfield University/FAA CAMI/others
- Each Source Provides Useful and Unique Data
  - e.g. experiments more useful for validation than accident reports
- FSEG Undertaking Large Data Extraction Exercise From *All THREE* Sources

FSEG Evacuation Data Collection

Overturned rail carriage

hospital

public event

Full-scale ship evacuation

Ship evacuation simulator

Aircraft evacuation

THE EXODUS SOFTWARE

- **EXODUS:** *software tools used to simulate behaviour and movement in large complex spaces.*
- R&D on EXODUS began around 1989.
- EXODUS is currently used in over 20 countries.
- Four versions currently available :
  - **airEXODUS** : aircraft applications
  - **buildingEXODUS** : built environment
  - **maritimeEXODUS** : marine applications
  - **vrEXODUS** : VR animation tool

FSEG

Examples of EXODUS Applications

Dusseldorf Airport

Royal Ascot

Millennium Dome

Thames River Boat

High speed craft

Stadium Australia

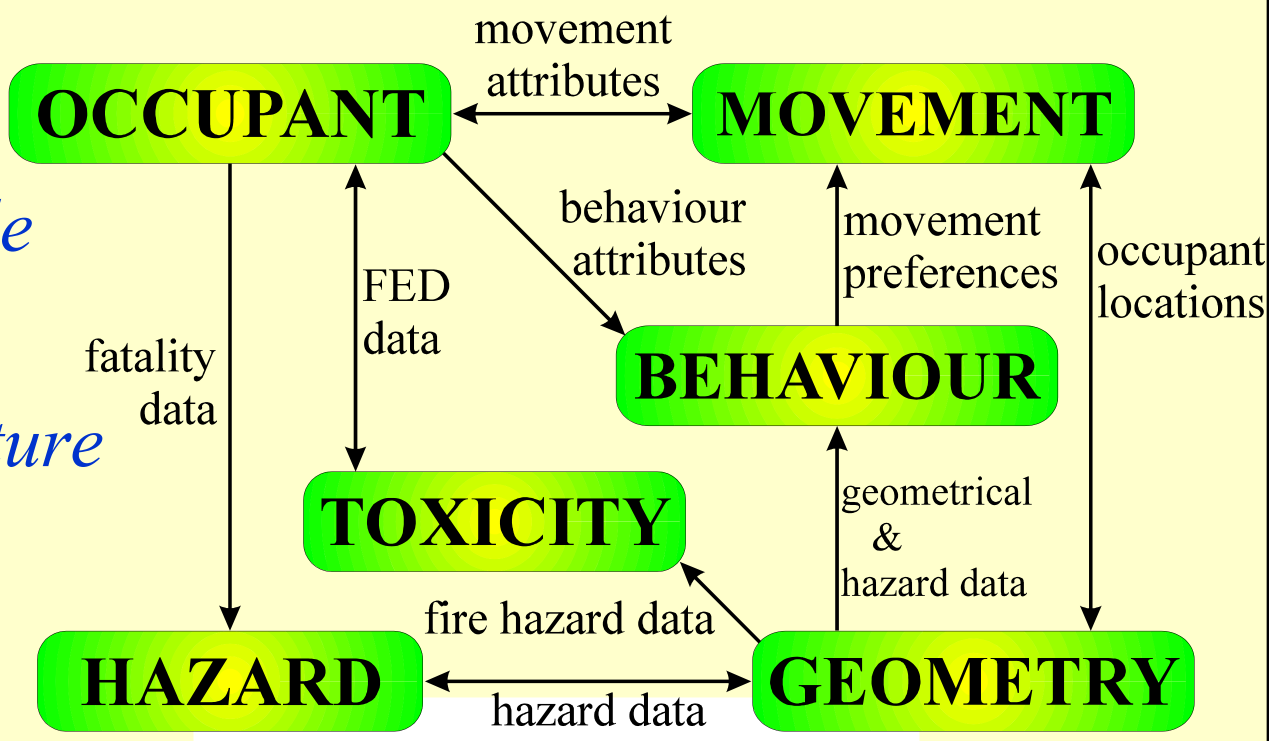
EXODUS Model

Considers

People-People

People-Fire

People-Structure



•Behaviour model is Rule Based and Adaptive.

Use of Certification Data

- airEXODUS makes use of the *passenger exit delay time* parameter
  - ***exit hesitation time + exit negotiation time***
- Certification trial data extraction exercise has provided 20 Type-A exits with *Assertive* Cabin Crew suitable for this analysis, involving 2078 paxs, from 11 aircraft.
  - **A310 (255 pax), A310 (280 pax), B747,B747-300, B747-SR, B767-300, B767-346, B777-200 (420 pax), B777-200 (440 pax), DC10, MD11**
- Data also available for unassertive and in-between crew.
- In addition, have extracted data for Type-III, Type-I, Type-B and Type-C exits.
- Certification data also used to set exit ready times.

airEXODUS Validation

- airEXODUS has undergone a range of validation trials including:
  - Comparison with Cranfield trials,
  - Blind comparison with certification trial,
  - Comparison with other certification trials.
- In the latest study, as part of a CAA funded project, airEXODUS predictions were systematically compared with a range of past certification trials.
- These included wide and narrow body aircraft.
- Here we present a summary of the results from the wide-body trials.

Wide-Body Aircraft Validation Study

- 4 aircraft selected, 3 belong to a derivative family, the 4th is an unrelated aircraft.
- **Case 1**: 256 passengers, evacuation time - **83.7 s**
  - exit configuration: Type-A, Type-III and Type-A
- **Case 2**: 285 passengers, evacuation time - **72.6 s**
  - exit configuration: Type-A, dual Type-III and Type-A
- **Case 3:** 351 passengers, evacuation time – **71.7 s**
  - exit configuration: Type-A, Type-A, Type-I, Type-A
- **Case 4:** 440 passengers, evacuation time – **74.4 s**
  - exit configuration: Type-A, Type-A, Type-A, Type-A
- ***Time = out of aircraft time for passengers***.

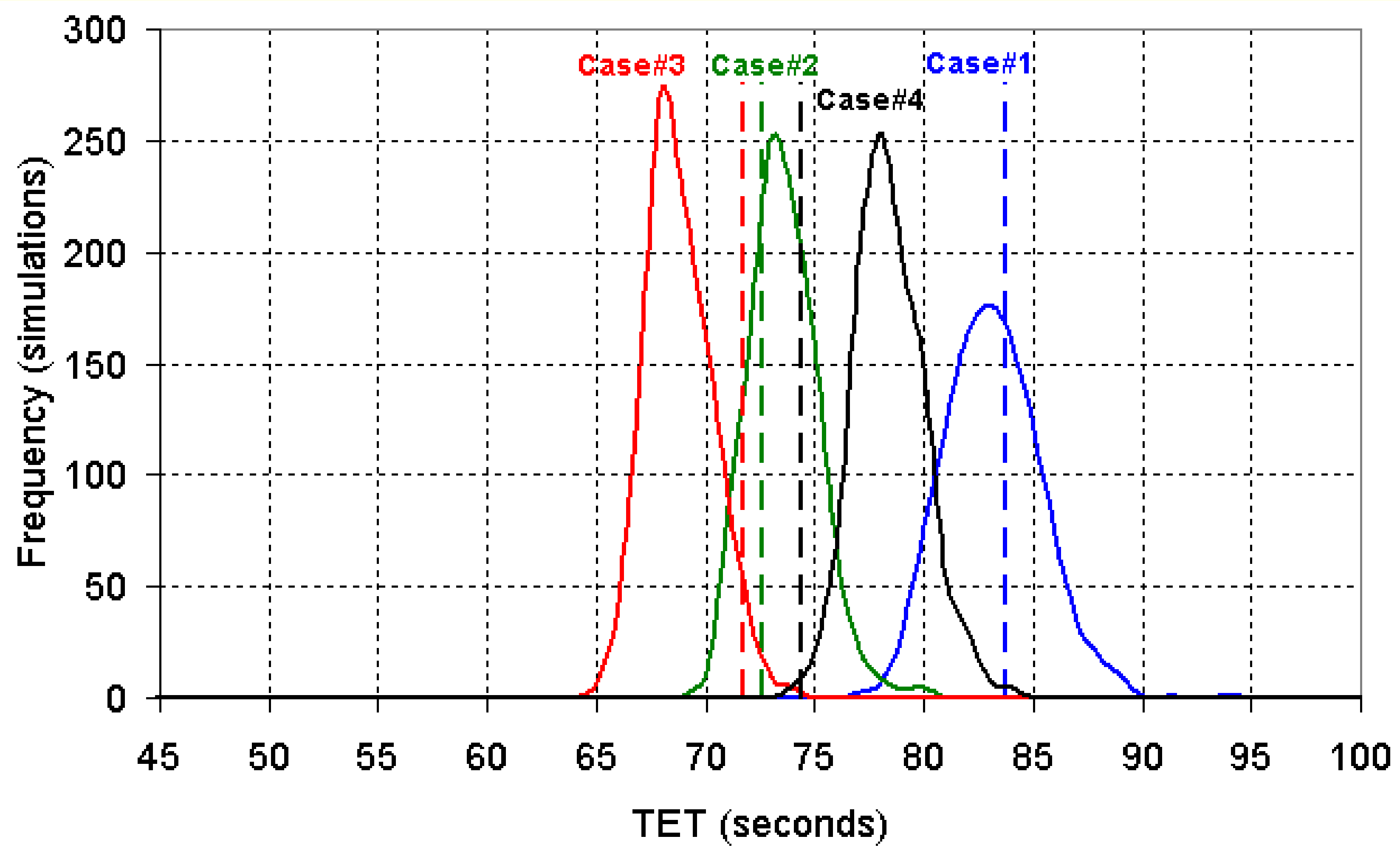
airEXODUS Model Specification

- Aircraft geometries built from detailed drawings.
- Paxs specified using certification mix profile.
- All cases are run under certification type evacuation conditions involving:
  - Half the total number of aircraft exits,
  - Assertive cabin crew located at each Type-A/I exit,
  - Orderly passenger behaviour of the type found in certification evacuations,
  - Each exit being made ready in a representative time derived from past relevant certification trials.

airEXODUS Model Specification

- airEXODUS ***extreme*** behaviour disabled.
- For each case, airEXODUS run 1000 times without changing model parameters.
  - *Generates a probability distribution of possible evacuation times, not a single value!*
- airEXODUS set to produce optimal performance under the set conditions.
  - attempts to balance the number of pax heading for various exits in an attempt to have exits finish at the same time,
  - not always achieved and some simulations produce sub-optimal performance,
  - results thus suggest the best performance that is likely to be achieved.

airEXODUS Frequency Distribution



airEXODUS Validation Results

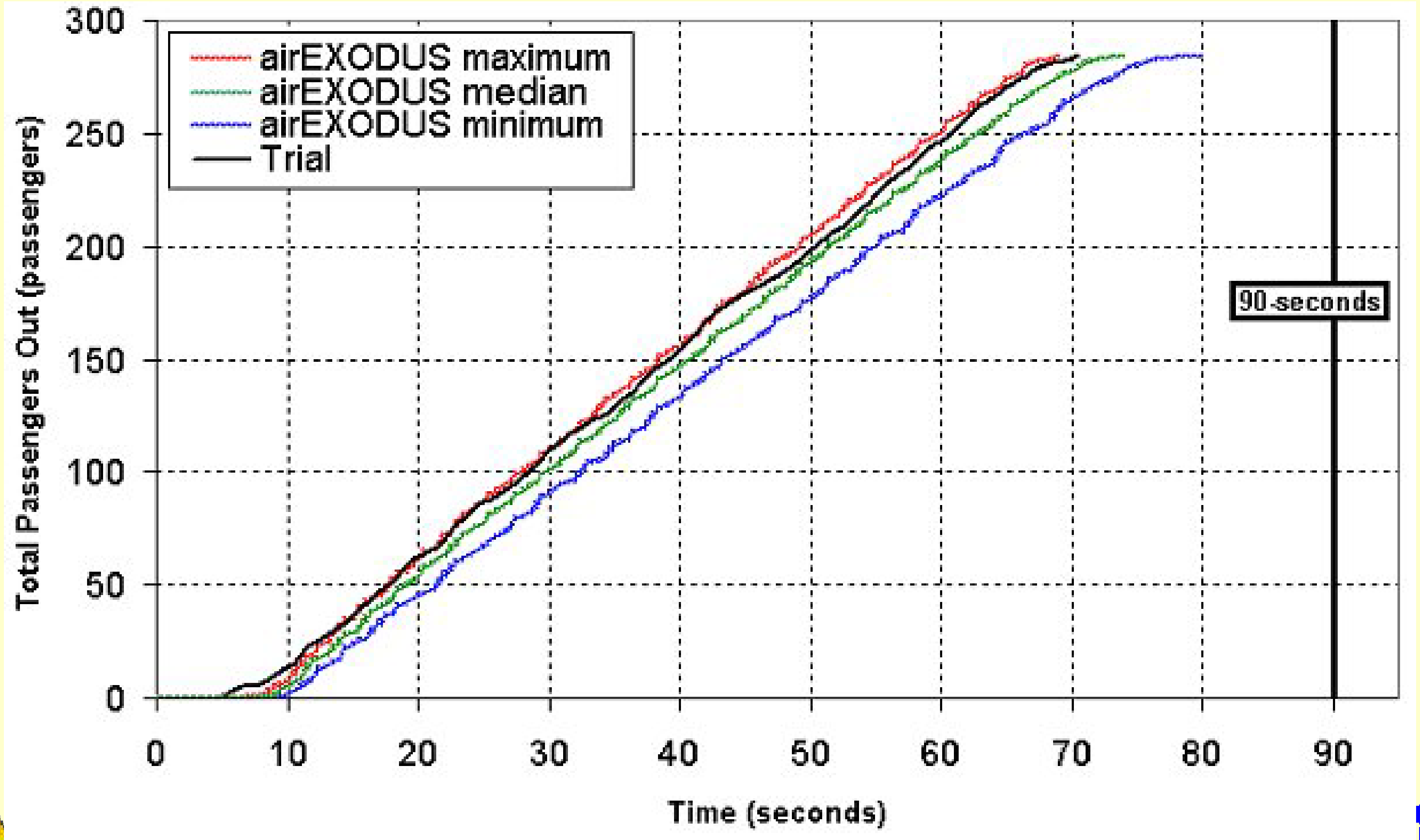
Aircraft Case	Trial Result (s)	airEXODUS Mean (s)	Trial Rank	airEXODUS Rank
Case 1	83.7	82.7	4	4
Case 2	72.6	73.1	2	2
Case 3	71.7	68.3	1	1
Case 4	74.4	77.9	3	3

airEXODUS Validation Results

	Case 1	Case 2	Case 3	Case 4	Mean absolute difference
% Diff between airEXODUS mean and trial	1.2	-0.8	4.7	-4.7	2.8 %
Diff between airEXODUS mean and trial (seconds)	1.0	-0.5	3.4	-3.5	2.1 s
Trial falls within airEXODUS distribution	yes	yes	yes	yes	N/A

- These comparisons are based solely on the end point i.e. the final evacuation time.
- How does the evolution of the evacuation compare?

airEXODUS cumulative exit times for Case 2



airEXODUS Validation Results

- To summerise:
  - airEXODUS predicted curves have a similar structure to the trial curve.
  - This indicates that the predicted evacuation evolution is similar to the actual trial evacuation.
  - With the exception of the start up period, trial curve falls within the predicted envelope for the entire trial.
  - Start up differences due to exit ready time used in simulations being different to that in trial.
  - Mean predictions within ***2.8%*** of measured
  - Maximum absolute difference ***4.7% (or 3.5 seconds).***
  - Rank order of aircraft performance preserved.

Exit Separation Analysis

- airEXODUS is used to explore the influence of exit separation on evacuation time.
- Current regulations state that:

"Exit pairs must be no more than 60 feet apart as measured longitudinally"

- Intuitively, exit separation is an important parameter in determining aircraft evacuation efficiency.
- However, before rules can be correctly established limiting exit separation, it is essential to understand the factors that influence evacuation efficiency.

Exit Separation Analysis

- Many factors will have an impact on relationship between exit separation and evacuation efficiency:
  - number of pax, type of exits, cabin layout, aircraft orientation, presence of fire/smoke, pax behaviour, etc.
- Requires a detailed systematic study of these factors and how they interrelate.
- As a first step, this study considers exit separation under the following conditions:
  - ***Type-A exits are used,***
  - ***Certification conditions are maintained,***
  - ***Maximum allowable number of passengers used***.

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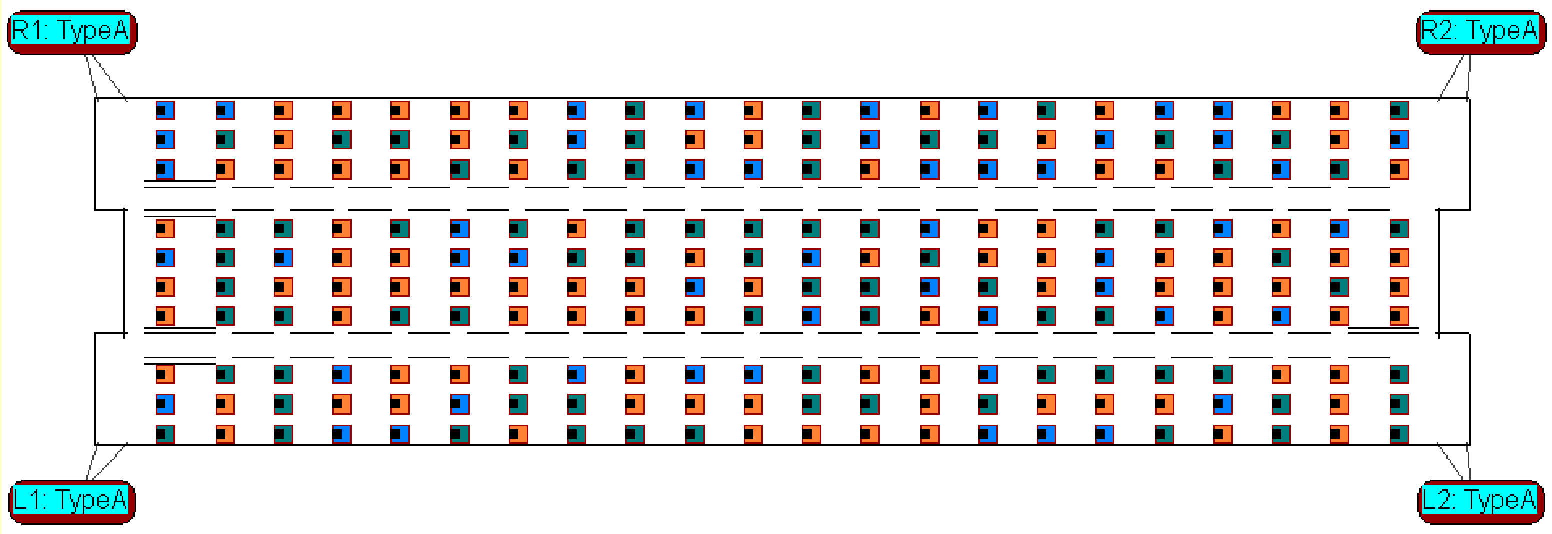
Analysis study

- The test section studied involved:
  - A wide body cabin section,
  - Max pax capacity i.e. 220 pax seats,
  - Four Type-A exits
- The base case configuration is **regulatory compliant** with 60 feet between exits.



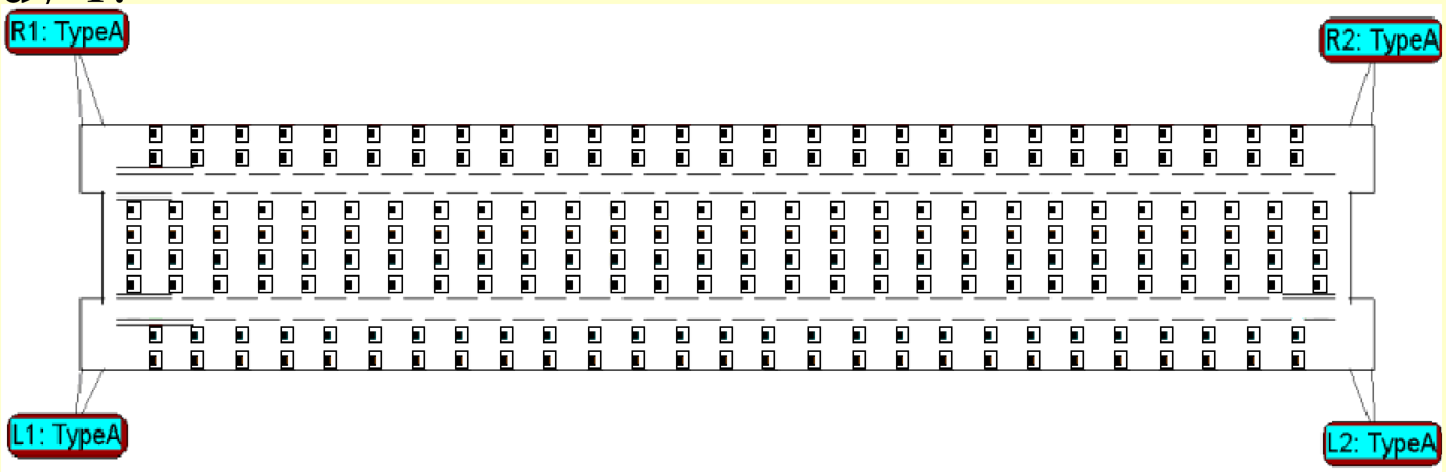
Analysis study

•Three sets of studies conducted:

•**STUDY 1:** A single exit from each exit pair available, stretch the cabin section without increasing pax numbers and note change in evacuation times.

•**STUDY 2:** Two exits available in a single exit pair and stretch cabin section as in study 1.

•**STUDY 3:** Seating changed from 3-4-3 to 2-4-2 and repeat study 1.

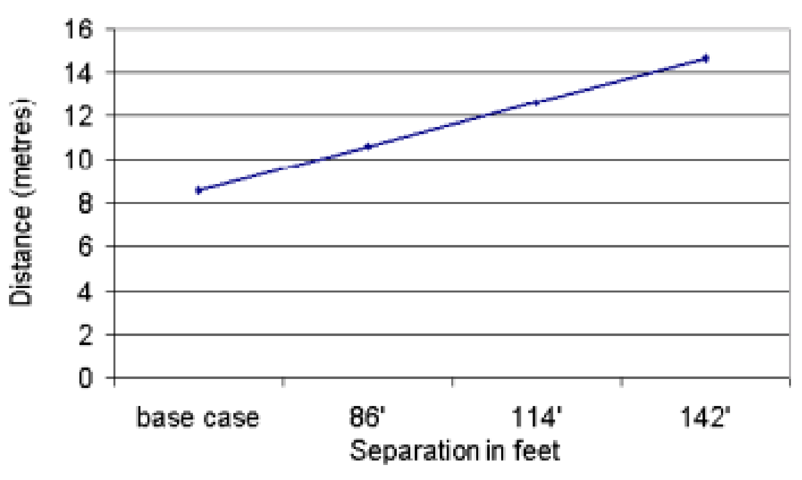


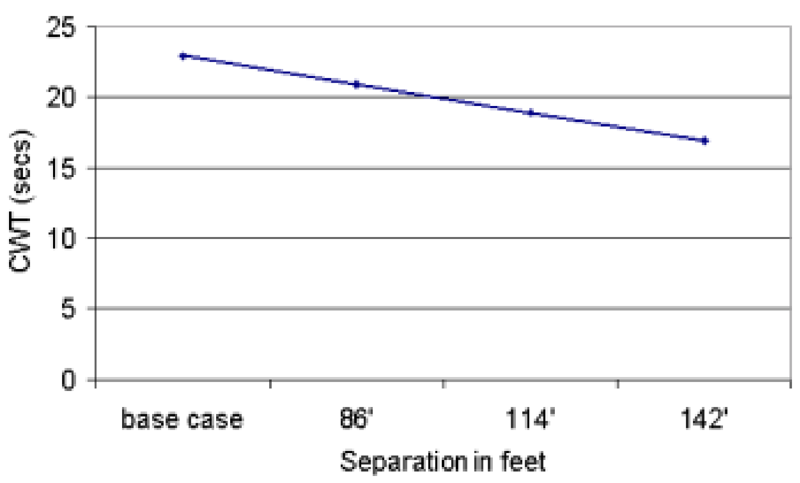
Analysis Method

- Only results from Study 1 presented here. See paper for information regarding more detailed report or send email to **e.r.galea@gre.ac.uk**
- Incrementally stretch the cabin section
  - 60ft, 86ft, 112ft….390ft
- Cabin stretched beyond realms of practicality.
- This is necessary to fully understand relationship between exit separation and evacuation efficiency.
- An iterative analysis
  - Many repetitions to capture stochastic differences
  - Many different population configurations to capture positional variations

Study 1: Certification Case

Results of the 60ft, 86ft, 114ft and 142ft

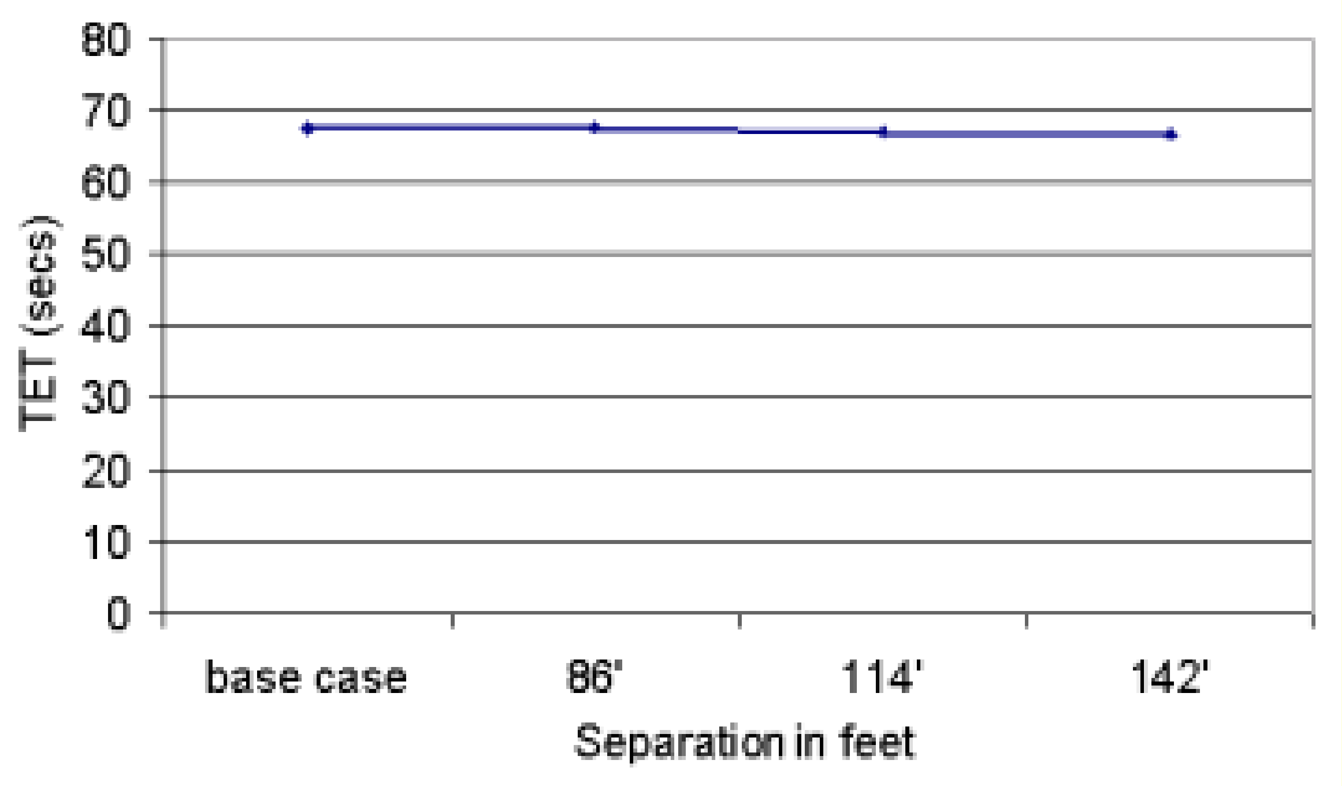




- Average Distance Travelled by paxs increases as cabin is stretched

- Average Congestion experienced by paxs decreases as cabin is stretched

Study 1: Certification Case



• Average Total Evacuation Time remains almost constant as aircraft is stretched.

Study 1

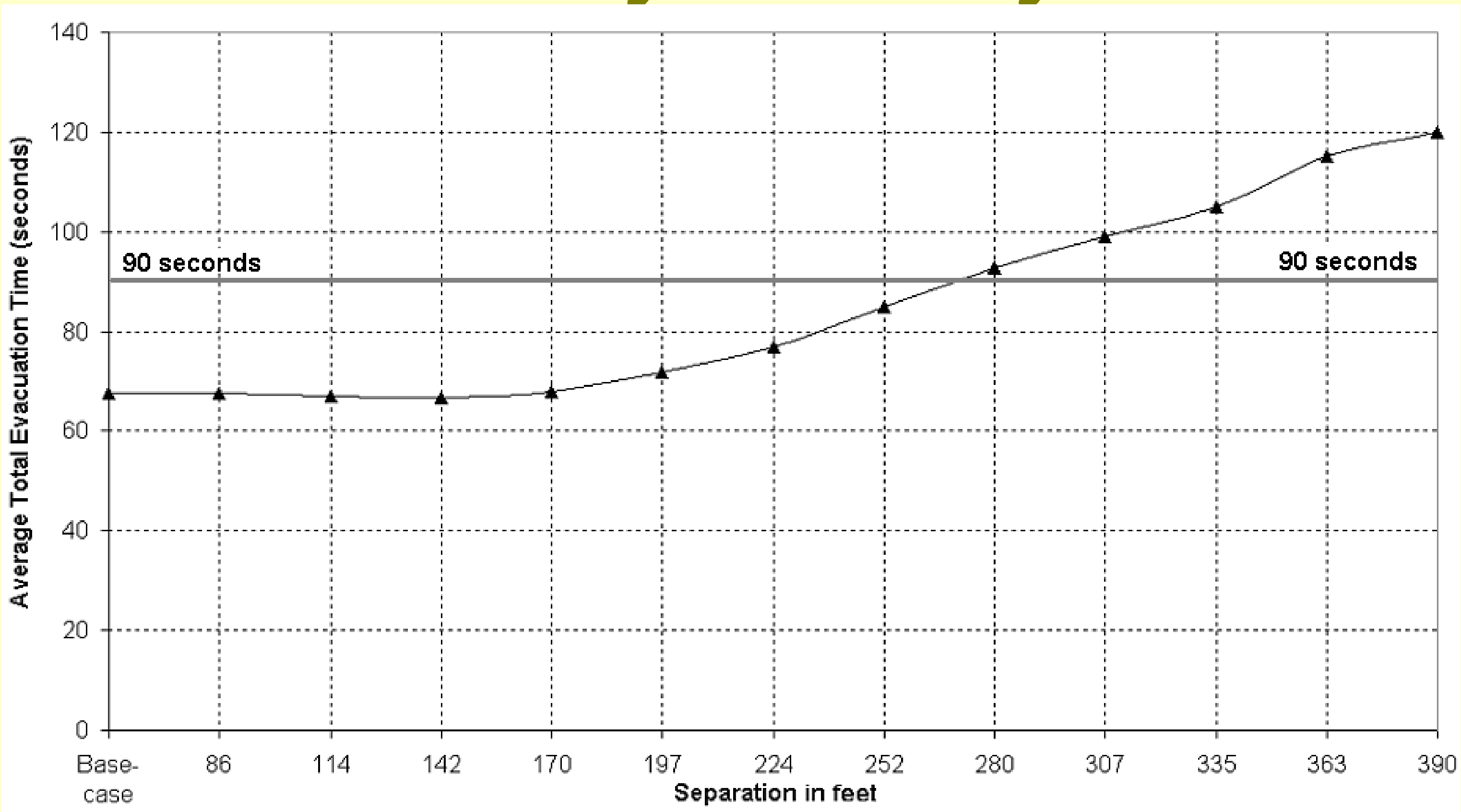
Question:

What should we expect if we continue to stretch the cabin section further?

Answer:

Expect congestion to decrease as passengers spend increasingly more time moving. Evacuation time should remain constant until exit congestion reduced to near zero at which point evacuation time will be a function of travel time and hence increase.

Analysis study



• Evacuation time is constant until a separation of approximately 170 feet

Analysis study

- ***However, congestion does not completely disappear!***
- Delays caused by congestion in cabin are made up of at least three observable components:
  - exit queue congestion
  - seat row congestion
  - sub-queue congestion
- All contribute to total evacuation times but significance of each component varies as cabin is stretched.
- For moderate stretches, exit queue congestion dominates
- As stretch increases, exit queue congestion and seat row congestion decrease but sub-queue congestion plays a more dominant role.

Exit Separation Results

- To summerise:
  - for the conditions examined, an exit separation of ***170 feet*** is the '***practical exit separation threshold***' for Type-A exits that cannot be exceeded without an adverse effect on evacuation times.
  - maximum ***practical exit separation threshold*** is scenario dependent,
  - This is not to say that it is acceptable to have exit separations up to 170 feet,
  - a complex relationship exists between exit separation and evacuation efficiency.

- Makes it difficult to set meaningful prescriptive exit separation limits

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Certification Issues / Validation

- It should be recognised that no level of validation will ***PROVE*** a model correct. However, confidence in the model is established the more often it is shown to be capable of producing reliable predictions.
- Success of airEXODUS in current and previous validation exercises is a compelling argument for the introduction of a certification role for computer models - at least for derivative aircraft.
- Can/should be considered ***NOW*** as a legitimate and powerful aid in design applications.

Certification Issues / Data Requirements

- Where data exists in the historic record this can easily be incorporated within evacuation models with confidence.
- airEXODUS has incorporated data from the majority of previous wide and narrow body aircraft trials.
- Data must be statistically meaningful.
- However, even in the historical record there is insufficient data for some of the more ***"unusual"*** exit configurations found on smaller aircraft.

Certification Issues / Data Requirements

- Under these circumstances or when truly new structural features are incorporated within a design it is **ESSENTIAL** to perform thorough **component testing** under strict certification conditions in order to derive necessary data, for example:
  - Type X exit, (i.e. totally new exit concept) or
  - Type A exit with a sill height exceeding all previous use or
  - Type A exit with an unusual slide configuration that impacts exit hesitation time.

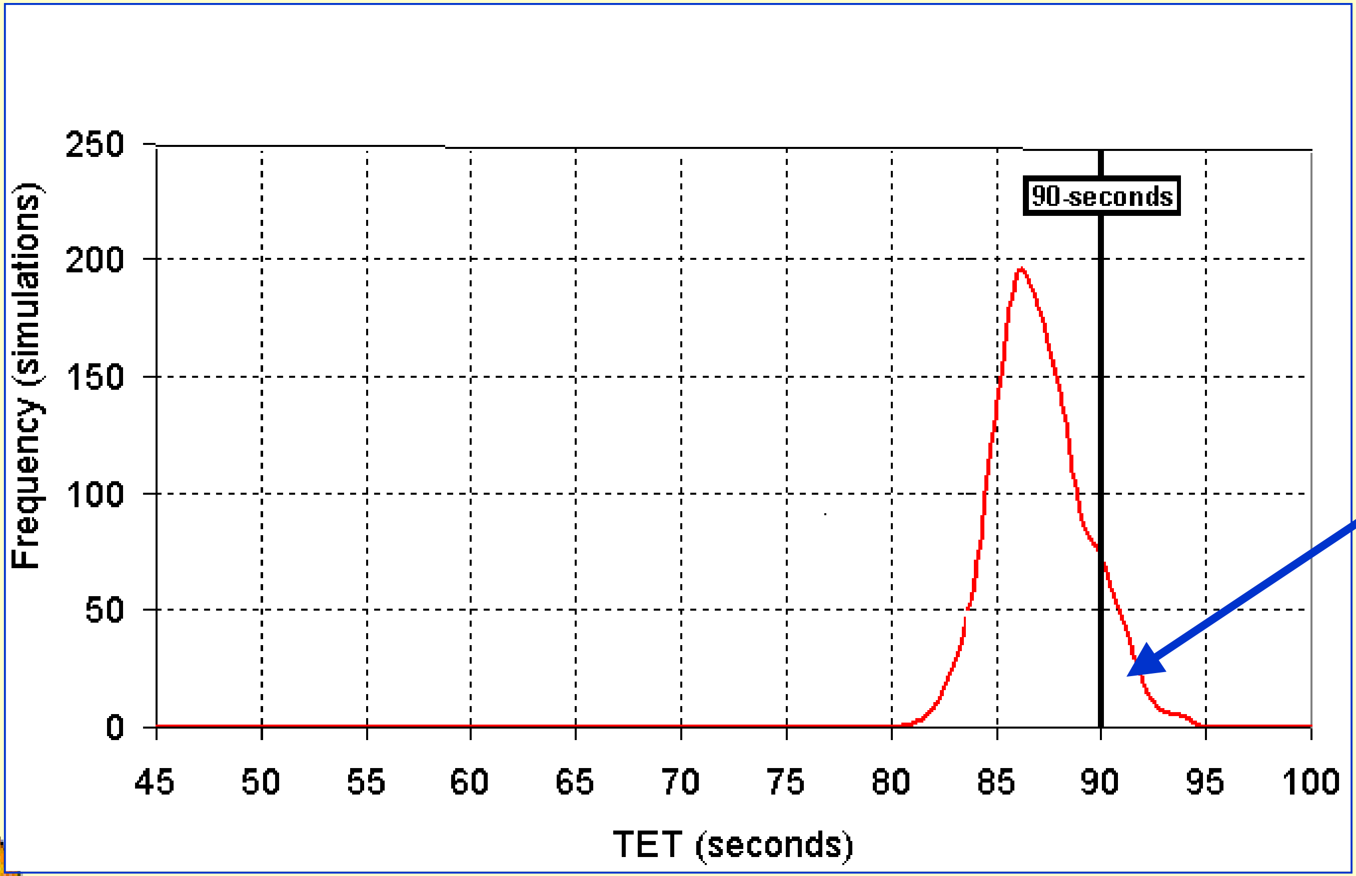
Certification Issues / What to Examine?

- **Evacuation models have the capability of examining many different types of scenarios.**
- **What scenario should be considered for certification purposes?**
  - **Do we simply keep the current certification scenario?**
  - **With tools such as *AASK* and *SAD*, thorough accident analysis is possible. Should we use information gained from accident analysis to define the certification scenario?**
  - **If so, do we select the most likely evacuation scenario or the most likely "severe" evacuation scenario?**
  - **Should the certification process involve a range of challenge scenarios e.g. different exit availability?**
  - **Should the certification process be aircraft type specific? Is it likely that a high wing turbo prop commuter aircraft will suffer the same type of accident/evacuation scenario as a very large wide body multi jet aircraft? Accident analysis should assist in providing the answer to these questions.**

Certification Issues / What Constitutes Acceptance?

- Unlike full-scale testing, evacuation models allow the possibility of performing many repeat simulations for any one scenario thereby producing a range of results for the one case.
- What should be considered ***"deemed to satisfy"?***
- Should 100% of the results be sub-90 seconds?
- Should the 95% percentile result be sub-90 seconds?
- Should the median (i.e. 50%) or mean be sub-90 seconds?

Certification Issues / What Constitutes Acceptance?



5% of trials over 90 s

Certification Issues / What Constitutes Acceptance?

- An alternative approach is to examine the historic record and perform repeated simulations of all the aircraft that have been deemed acceptable by society.
- Inevitably some of these aircraft will produce distributions with tails over 90 seconds.
- This analysis would identify the range of cut-off points that has proved previously acceptable.
- From this an acceptable cut-off point could be established.

Certification Issues / What Constitutes Acceptance?

- Example: 3 of the 4 wide body aircraft examined in this paper generated no simulations in excess of 90 seconds.
- However, for Case 1, 3 of the 1000 simulations produced times slightly in excess of 90 seconds.
- This suggests that for this aircraft 99.7% of the simulations satisfied the requirement.
- As this aircraft is deemed to be acceptable, this suggests the acceptance criteria could be considered to be 99.7%
- If this general approach were acceptable, the analysis would need to be repeated for all aircraft that have passed.
- Also note that the evacuation analysis did not produce on-ground times but out of aircraft times. Slide times should be added to the evacuation times described here.

Certification Issues / What Constitutes Acceptance?

- Alternatively, attempt to mimic the certification process of only producing a single data point.
- From the model generated probability distribution select a single evacuation time at random.
- This would be the “official” certification time which must be sub 90 seconds in order to pass.
- This approach offers parity with the current certification process and circumvents the need to redefine the acceptance level.
- Unfortunately, it also fails to capture the full potential of the data generated by the analysis.

Certification Issues / Performance based certification

- Does 90 seconds actually have any relevance?
- With the development of analysis tools, perhaps we should be adopting **RISK ANALYSIS** as part of a **PERFORMANCE BASED** certification process?
- In the building industry similar issues have been tackled in the move from Prescriptive to Performance based certification.
- Concept involves determining Available Safe Egress Time or **ASET** and Required Safe Egress Time or **RSET**.
- ASET and RSET determined from models and data.
- These are scenario based and determined on a case by case basis by the regulator and design team.
- **ASET > RSET** for design to be acceptable.

Concluding Comments

- airEXODUS was able to predict the results of four certification trials with
  - a mean difference of ***2.8%***
  - the measured evacuation time of the certification trial within the bounds of predictions
  - the general rank order of trial times being matched by predicted rank order
  - the cumulative exit curves produced during the trials falling within the predicted window
- Suggests airEXODUS is capable of predicting similar chain of events to that which occurred during the certification trials.

Concluding Comments

•For the ***population and cabin section investigated and under certification conditions***, exit separations of ***60** to **170** feet* resulted in approximately constant total evacuation times and personal evacuation times.

•*This is not to say that in designing a "safe" aircraft it is acceptable to have exit separations greater than 60 feet.*

•Not advisable to mandate a maximum exit separation without taking into account, exit type, exit availability, occupancy load, aircraft configuration and issues associated with nature of accident scenario.

•To take all these factors correctly into account requires a Performance based certification process.

Concluding Comments

- Evacuation models have the potential to enhance the current 90 second certification practice.
- Success of airEXODUS at predicting evacuation performance of aircraft in certification trials is a compelling argument for the adoption of models for certification - at least for derivative aircraft.
- If truly new features are to be included in design, it is ESSENTIAL to include component testing with modelling.
- Models also have a role to play in rule making. Can be used to provide insight into complex issues such as exit separation.

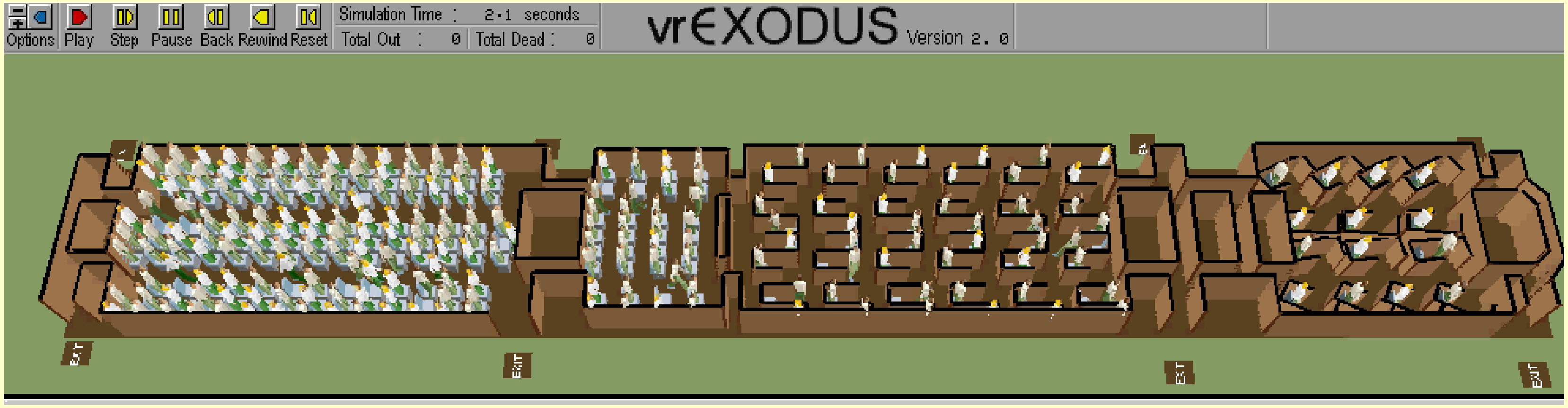
Suggested Additional Exit Separation Analysis

- Examine impact of centrally located exits.
- Examine the effect of lower occupancy loads.
  - i.e. 90% full, 80% full, etc…
- Examine the impact of different exit types.
- Examine the impact of single aisle.
- Examine the impact of reduced pax mobility.
- Examine the impact of fire products.
- Examine the impact of non-level floor (e.g. due to gear failure).

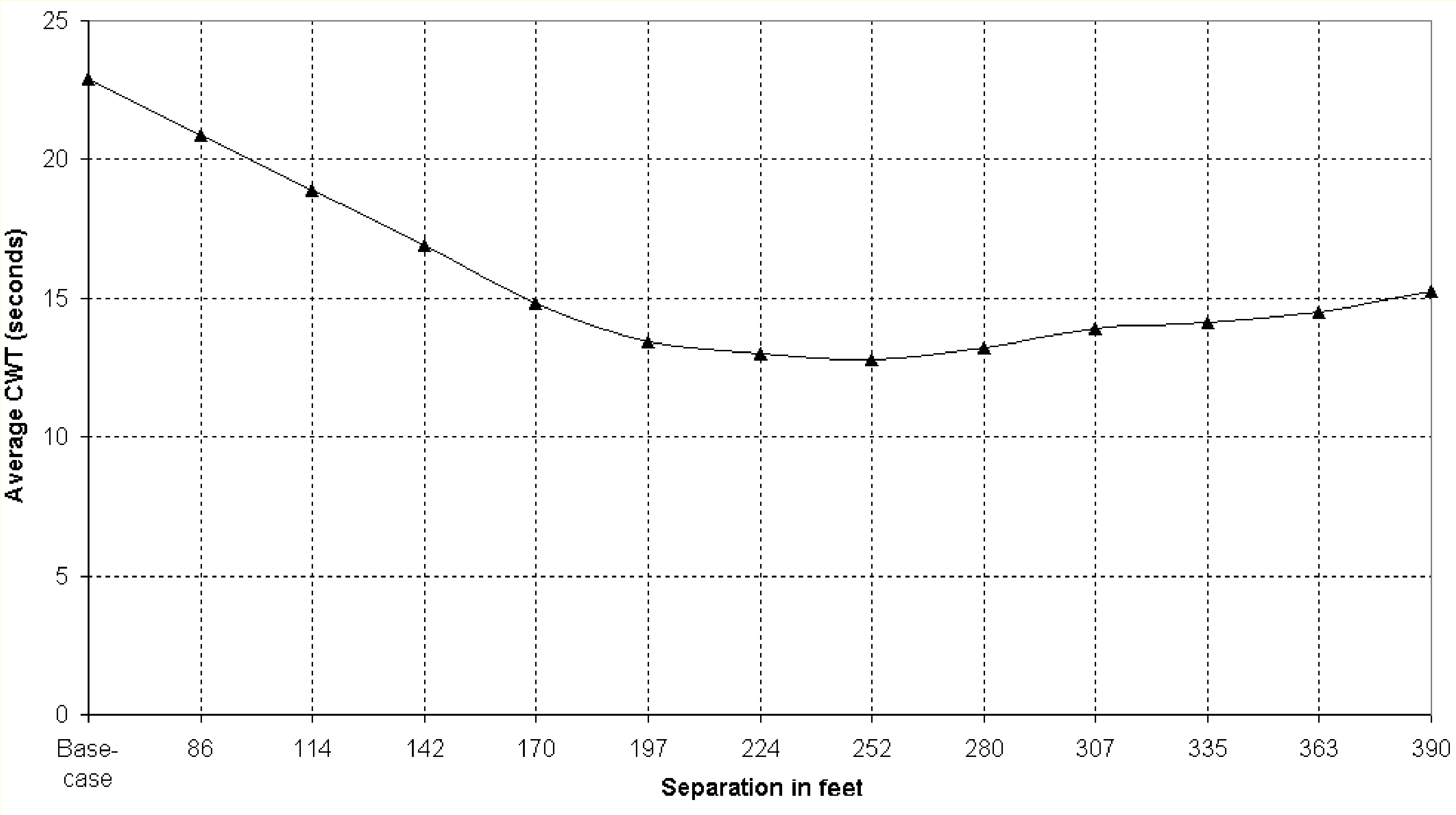
Further Work

•Research is underway to develop additional crew/passenger interactions such as crew and passenger initiated by-pass.

Identify issues related to crew management, assist in developing procedures and demonstrate in training



Analysis study: CWT



- **CWT remains at approximately 15 seconds**