

**Impact case study (REF3b)**

<b>Institution:</b> University of Greenwich
<b>Unit of Assessment:</b> (UoA 12) - Aeronautical, Mechanical, Chemical and Manufacturing Eng.
<b>Title of case study:</b> Fire Safety Engineering Group (FSEG) evacuation research
<p><b>1. Summary of the impact</b></p> <p>The Fire Safety Engineering Groups (FSEG's) research related to human behaviour associated with evacuation and evacuation modelling is saving lives because it is used to design safer aircraft, ships and buildings. Its Economic impact stems from licensing the EXODUS software to 250 organisations in 32 countries and commercial applications of the software which enable the realisation of cutting-edge designs and enabling the continual safe use of heritage structures such as the Statue of Liberty. Public Policy impact stems from FSEG aviation research influencing Australian government aviation safety policy while impact on Practitioners is a result of changes to international maritime guidelines based in FSEG research and the wide scale use of the EXODUS software by engineers around the world. Society impact results from its research featuring in a number of popular documentary programmes attracting audiences measured in the millions.</p>
<p><b>2. Underpinning research</b></p> <p>Research into human behaviour and evacuation modelling at the University of Greenwich started in 1991 with a focus on understanding human behaviour in aircraft evacuation. Its aim was to develop a modelling tool that could predict the behaviour of passengers subjected to a post-crash fire. This early work led to the development of the world's first microscopic evacuation model that coupled fine grained spatial resolution, human behaviour, toxicological models and fire hazard data [3.1] – an early prototype of the airEXODUS software. The continuing research was supported through a series of research grants from the EPSRC [3a] and UK CAA [3b] aimed at developing the prototype into a practical engineering tool. The EPSRC project and a CAA project were aimed at improving the understanding of human behaviour in aviation accidents. This consisted of extracting survivor accounts of evacuation experience from aircraft crashes and the development of a relational database of these experiences – AASK database [3.2]. This study identified that the introduction of complex human behaviour was essential if evacuation models were to accurately predict evacuation dynamics. The second CAA project consisted of extracting human performance data from video footage of evacuation certification trials – enabling human performance during evacuation to be quantified. This work resulted in the publication of many papers quantifying and explaining human behaviour in aviation accidents and formed the basis for further development of airEXODUS, ensuring that the behaviour represented in the model was realistic. The third CAA funded project supported the development of the world's first practical engineering tool to simulate aircraft evacuation – airEXODUS [3.3]. This built on the early prototype and the human behaviour and performance data extracted from accidents and certification trials. Research continued to be funded through a series of EU funded research projects [3c, 3d] and a number of research projects funded by the aircraft industry [3e, 3f].</p> <p>From 1994, FSEG research into human behaviour expanded to include the built environment. The agent based modelling concept using a fine spatial mesh that was used to simulate aircraft evacuation was adapted to simulate evacuation of people from building environments [3.4]. This required the modelling approach to be extended to represent stairs, the behaviour of people on stairs and various mathematical approaches to represent route finding, interaction with signage, group behaviour, etc [3.5]. This research was funded through a variety of grants [3g-3i].</p> <p>From 1999 FSEG research expanded to include maritime environments. The ship environment while similar to that of buildings poses additional challenges, such as a heeled deck, the impact of lifejackets on human performance, etc. Much of this behaviour was unknown and not quantified posing significant difficulties for model development. To collect human performance data of people on inclined decks i.e. static heel/trim, a large-scale simulator (SHEBA) was constructed in Canada [3.6]. Further research into human behaviour measured the time required by passengers on ships at sea to respond to the alarm and begin the evacuation process [3.7], an essential parameter in evacuation modelling. Data generated from this work was used in the development of maritimeEXODUS [3.5]. This research was funded through a variety of grants [3j-3k].</p>
<p><b>3. References to the research</b> (REF1 submitted staff in <b>bold</b>, and Filippidis, Deere, Xie are being submitted to other UOA's).</p>

## Impact case study (REF3b)

- 3.1 **Galea, E. R., & Galparsoro, J. P.** (1994). A computer-based simulation model for the prediction of evacuation from mass-transport vehicles. *Fire Safety Journal*, 22(4), 341–368. [http://dx.doi.org/10.1016/0379-7112\(94\)90040-X](http://dx.doi.org/10.1016/0379-7112(94)90040-X)  
Galea was a staff member in the UoG Math Dept and Galparsoro was an MSc project student.
- 3.2 **Galea, E. R., Finney, K. M., Dixon, A., Siddiqui, A., & Cooney, D.P.** (2005). An analysis of the passenger to cabin crew ratio and exit reliability based on past survivable aviation accidents. *Human Factors and Aerospace Safety*, 5(3), 239–256. Retrieved from <http://trid.trb.org/view.aspx?id=786307>  
All authors were members of FSEG, with Galea being a Prof and group leader and Finney being an academic member of staff. Dixon, Siddiqui and Cooney were research assistants.
- 3.3 Owen, M., **Galea, E. R., Lawrence, P. J., & Filippidis, L.** (1998). The numerical simulation of aircraft evacuation and its application to aircraft design and certification. *Aeronautical Journal*, 102(1016), 301–312. Retrieved from <http://cat.inist.fr/?aModele=afficheN&cpsidt=2335655>  
All authors were members of FSEG, with Galea being a Prof and group leader, Lawrence is a Reader, Filippidis and Owen were research assistants. This paper won the best paper award from the Royal Aeronautical Journal – The Hodgson Prize in 1999.
- 3.4 Owen, M., **Galea, E. R., & Lawrence, P. J.** (1996). The EXODUS evacuation model applied to building evacuation scenarios. *Journal of Fire Protection Engineering*, 8(2), 65–84. <http://dx.doi.org/10.1177/104239159600800202>  
All authors were members of FSEG, with Galea being a Prof and group leader, Lawrence is a Reader, and Owen was a research assistant.
- 3.5 Xie, H., Filippidis, L., **Gwynne, S., Galea, E. R., Blackshields, D., & Lawrence, P. J.** (2007). Signage Legibility Distances as a Function of Observation Angle. *Journal of Fire Protection Engineering*, 17(1), 41–64. <http://dx.doi.org/10.1177/1042391507064025>.  
All authors were members of FSEG, with Galea being a Prof and group leader, Lawrence is a Reader, Gwynne and Xie are Post-Docs, Filippidis and Blackshields are research assistants. Xie was a doctoral student who now has a PhD and based part of his doctoral thesis on this work.
- 3.6 **Galea, E. R., Filippidis, L., Gwynne, S., Lawrence, P. J., Sharp, G., & Blackshields, D.** (2002). The Development of an Advanced Ship Evacuation Simulation Software Product and Associated Large Scale Testing Facility for the Collection of Human Shipboard Behaviour Data (pp. 37–50). Presented at the Proceedings of the International Conference on Human Factors in Ship Design and Operation, The Royal Institution of Naval Architects, London. Retrieved from <http://www.opengrey.eu/item/display/10068/668128>  
All authors were members of FSEG, with Galea being a Prof and group leader, Lawrence is a Reader, Gwynne is a Post-Doc, Filippidis, Sharp and Blackshields are research assistants.
- 3.7 **Galea, E. R., Deere, S., Sharp, G., Filippidis, L., Lawrence, P. J., & Gwynne, S.** (2007). Recommendations on the nature of the passenger response time distribution to be used in the MSC 1033 assembly time analysis based on data derived from sea trials. *International Journal of Maritime Engineering*, 149(A1), 15–29. Retrieved from <http://gala.gre.ac.uk/id/eprint/1076>  
All authors were members of FSEG, with Galea being a Prof and group leader, Lawrence was a Reader, Gwynne was a Post-Doc, Filippidis and Sharp were research assistants and Deere was a doctoral student who now has a PhD and based part of his doctoral thesis on this work.

### EXAMPLE RESEARCH GRANTS:

- 3a E. R. Galea. *Fire and evacuation in aircraft environments*. EPSRC Grant (GR/K38250). 1996-1998. £41k.
- 3b E. R. Galea. *AASK database*. UK CAA Grant (255/SRG/R&AD). 1998-2000. £115k;  
E. R. Galea. *Certification database*. UK CAA Grant (049/SRG/R&AD). 1996-1999. £106k;  
E. R. Galea. *airEXODUS development*. UK CAA Grant (7D/S/923/1and2). 1997-1999. £113k.
- 3c E. R. Galea. *VELA - Very Efficient Large Aircraft*. EU FP5 (G4RD-CT2002-00842). 2002-2004. £130k (UoG component).
- 3d E. R. Galea. *NACRE* (Project concerned with fire+evacuation analysis of Blended Wing Body aircraft). EU FP6 (project 516068). Apr 2005 – Mar 2009. €590,000.
- 3e E. R. Galea. AIRBUS (France/Germany) funded research into aircraft configuration options for the A380. 1999-2001. £170k.
- 3f E. R. Galea. AIRBUS (France/Germany) funded analysis of A380 evacuation capabilities. Dec 2005 – Mar 2006. £31k.
- 3g E. R. Galea. *Study of the evacuation of the World Trade Centre buildings on 9/11/01*. UK

## Impact case study (REF3b)

DTLR. 2002-2003. £50k.

3h E. R. Galea. *HEED Consortium (led by FSEG and Professor Galea involving Universities of Ulster and Liverpool. Project concerned the evacuation of the World Trade Centre)*. EPSRC (GR/S74201/01 and EP/D507790). Sept 2004 – Oct 2007. £1.5 million.

3i E. R. Galea. *AVATARS (Concerned with circulation analysis in stations)*. EU FP6 (project: 12462). Apr 2005 – Sept 2007. €177k.

3j E. R. Galea. *Crew behaviour in conditions of list*. UK MOD. 2001-2002. £60k.

3k E. R. Galea. *Ship Evacuation*. EPSRC (GR/T22100/1). 2004–2007. £256k.

The quality of this research is demonstrated through the award of national and international prizes:

- 2003/2004 European IST prize by the European Council of Applied Sciences, Technology and Engineering (Euro-CASE) for the development of the EXODUS suite of software.
- 2003 Royal Aeronautical Society Hodgson Prize for best paper on a safety topic for a publication Prof Galea co-authored, entitled, “Examining the effect of exit separation on aircraft evacuation performance during 90 sec certification trials”, which appeared in the *Aeronautical Journal* 2002.
- 2002 Queen’s Anniversary Prize, citation:

***“The University is a recognised world leader in the area of evacuation model development. Use of its software technology by businesses and public authorities greatly enhances public safety and its specialised training offers vital expertise to the user community worldwide.”***

- The 2001 RINA/LR Safer Ships Award (Royal Institution of Naval Architects/Lloyds Register).

- The 2001 British Computer Society award for IT 2001 for the development of EXODUS, citation:

***“The winners not only demonstrate technical innovation, but also show how technology can be used to benefit society at large....,” Judith Scott, Chief Executive of The BCS.***

1999 Royal Aeronautical Society Hodgson Prize for best paper on a safety topic for a publication Prof Galea co-authored, entitled, “The Numerical Simulation of Aircraft Evacuation” which appeared in the *Aeronautical Journal* in 1998.

### 4. Details of the impact

**1) Economic Impact:** During the assessment period, UoG has generated over £837,000 from licensing the EXODUS software to 250 licensees in 32 countries. These licensees, ranging from engineering consultancies, regulatory authorities and national laboratories, use the software to explore the evacuation safety of complex structures, ensuring that they are safe and fit for purpose thereby generating considerable consultancy income. Example projects that have used the EXODUS software include the Airbus A330-X, A340 and the initial design of the Airbus A380 [5.1]. FSEG and the airEXODUS software were used in the preliminary design of the multi-billion euro A380 where it was used to assist AIRBUS in selecting a configuration for the largest passenger aircraft in the world that would meet international regulatory requirements for evacuation [3e]. Towards the end of the design programme, Airbus again used FSEG and airEXODUS to de-risk the A380 full-scale evacuation certification trial, saving the manufacturer potentially millions of euro by identifying possible problems that may occur during the certification trial and ensuring that the A380 was a safe aircraft [3f, 5.1]. The A380 comfortably passed the evacuation certification trial and is an aviation success story flying with the worlds leading airlines. airEXODUS has also been used by the Canadian aircraft manufacturer BOMBARDIER to assess the evacuation capabilities of a number of their aircraft while still in the early design stages including the Dash8-400, C-Series regional jet and the T507 project, ensuring that the proposed configurations will meet international evacuation certification requirements [5.2]. airEXODUS was also recently (2010) used by JET AVIATION to demonstrate that a private VIP configured B747 and by Mitsubishi (2008) in the design of their new regional jet, would satisfy international evacuation certification requirements [5.3]. Thus airEXODUS is used to save aircraft manufacturers tens of millions of dollars/euros in wasted development costs and lost sales revenues by ensuring that the aircraft will pass the certification trial and thereby also ensures that the design is safe for the travelling public [5.1-5.3].

A unique version of buildingEXODUS is being incorporated within the security system of the Pentagon as part of project Pentagon Shield. This makes use of special software features e.g. parallel computing implementation, CBRN toxicity model capability to enable faster than real time determination of optimal evacuation routes for building occupants during an incident. Battelle/DoD/Hughes turned to FSEG and buildingEXODUS when US based evacuation software was found to be inadequate, potentially jeopardising a multi-million dollar project [5.4]. The EXODUS software tools provide fire engineering firms a competitive edge when bidding for

projects, allowing them to win important contracts, generating significant income for the companies. An example is the use of building EXODUS, under license, by Hughes Associates to undertake an assessment of the life safety and emergency management systems within the Statue of Liberty [5.4]. Following this assessment and remodelling work, the Statue of Liberty was reopened to the public by President Obama in 2009.

**2) Impact on Public Policy:** The AASK database was developed primarily to assist the design of better aircraft evacuation models by providing factual information on how people behave in real emergencies. It has also been used to inform international legislation on aircraft safety and airline staffing of cabin crew e.g., a paper based on AASK data providing a detailed analysis of cabin crew numbers and their effectiveness in controlling safe evacuation [3.2] was cited in an Australian Senate report as part of the Australian government debate concerning a proposal to reduce cabin crew numbers [5.5]. The research was again cited on the floor of the Australian Senate during the parliamentary debate concerning cabin crew staffing levels [5.6] and again in a House of Representatives Standing Committee report in 2011 [5.7]. The result has been to maintain the number of cabin crew required on Australian passenger aircraft, ensuring that the Australian aviation industry remains amongst the safest in the world.

**3) Impacts on Practitioners and Professional Services:** FSEG was the first to collect human factors data defining how quickly passengers respond to evacuation alarms on ships at sea during semi-unannounced drills [3.6]. This work demonstrated that the data used in the International Guidelines on Ship Evacuation Analysis in IMO MSC Circ 1033 was incorrect and could lead to an incorrect assessment of the suitability of a ship design for evacuation. The data and analysis was presented to and accepted by IMO at their Fire Protection subcommittee meeting (FP51) held in January 2007 and now forms part of the revised International Guidelines document, IMO MSC Circ 1238 [5.8]. The data incorporated in MSC Circ 1238 are used around the world in ship evacuation analysis to demonstrate that passenger ships can be safely evacuated [5.9]. As already stated under Economic impact, over the assessment period, the EXODUS suite of evacuation software has been used by over 250 licensees in 32 countries and so has become a standard engineering design tool for safety analysis, used by fire safety engineers around the world. The software is therefore having an impact on the engineering profession around the world [5.4].

**4) Impacts on Society, Culture and Creativity:** FSEG research into evacuation has engaged the public, informing them of our research, educating them concerning risks associated with fire and evacuation and how they can minimise those risks, as well as informing future industrial partners and policy makers. This has been achieved through several high profile TV and Radio programmes which have featured our research such as the BBC 'Horizon' documentary based on FSEG fire and evacuation research, entitled, "How to Survive a Disaster" (first broadcast 10/03/09 on BBC1 (<http://bbc.in/15noerY>) which attracted a 1.7 million viewer audience representing 7% of the audience that night (<http://bit.ly/17BHAJx>)). The concepts presented in this programme were considered so important; the US news programme ABC Nightline featured a story on its nightly news programme broadcast on 22/12/09 which drew on much of the material presented in the Horizon programme [5.10]. Other programs include the Channel 4 documentary "Terror at Sea" (first broadcast 31/01/12 on Channel 4, (<http://bit.ly/17BIXHU>)) which followed the sinking of the Costa Concordia. Prof Galea commented on evacuation issues associated with large cruise ships (the programme attracted a massive 3.4 million viewers (<http://bit.ly/17BJp1>)) which was followed up by an interview on BBC Radio 4 Today (4 March 2012, (<http://bit.ly/GAKPrP>)).

**5. Sources to corroborate the impact (indicative maximum of 10 references)**

- 5.1 Airbus Chief Engineer, France.
- 5.2 Bombardier Senior Designer, Concept Design Team, Canada.
- 5.3 Jet Aviation Senior Certification Engineer, USA/Switzerland.
- 5.4 Hughes Associates, Principal, USA.
- 5.5 Australian Civil Aviation Legislation Amendment Bill 2005, [http://add\\_bit\\_link](http://add_bit_link), page.16
- 5.6 Australian Hansard, No4, 10/05/06, 41<sup>st</sup> Parliament, page.125, <http://bit.ly/15R9qEf>
- 5.7 Standing Committee on Infrastructure and Communications (Australia), Finding the Right Balance, page 26, <http://bit.ly/1arxCv9>
- 5.8 International Guideline Document, IMO MSC Circ 1238 - <http://bit.ly/15W1tI9>, Annex2, p6
- 5.9 Director Centre for International Cooperation, National Maritime Research Institute, Japan.
- 5.10 <http://bit.ly/1h8jGwP>