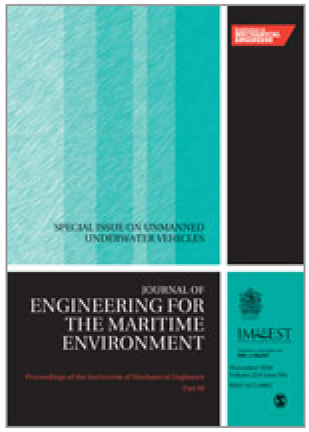

A Celebration of Academic & Industry Collaboration: The RNLI and Maritime Engineering Innovation

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Complete List of Authors:	Blake, James; University of Southampton, Faculty of Engineering and Physical Sciences, School of Engineering, Maritime Engineering Boyd, Stephen; University of Southampton, Faculty of Engineering and Physical Sciences, School of Engineering, Maritime Engineering Phillips, Holly; RNLI Trask, Richard; University of Bristol, Bristol Composites Institute (ACCIS) Cripps, Robert; University of Southampton, Faculty of Engineering and Physical Sciences, School of Engineering, Maritime Engineering
Keywords:	RNLI, RNLI ATP, bibliometrics, search and rescue craft, lifeboats
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A Celebration of Academic & Industry Collaboration: The RNLI and Maritime Engineering Innovation

Blake, J.I.R.[a,*], Boyd, S.W.[a], Phillips, H.J.[b], Trask, R.[c], Cripps, R.M.[a]
[a]Maritime Engineering, University of Southampton, UK, SO16 7QF
[b]RNLI, West Quay Road, Poole, Dorset, UK, BH15 1HZ
[c]Bristol Composites Institute (ACCIS), University of Bristol, UK, BS8 1TR

Abstract

Search and rescue (SAR) craft have to endure the toughest conditions in order to save lives at sea. The design, resourcing, operation and support of a SAR fleet requires state-of-the-art technology and an ability to react to and exploit cutting edge research and foment future research agenda. This paper reviews the unique relationships that exist between the Royal National Lifeboat Institution (RNLI) and academia to drive engineering innovations to the forefront of RNLI search and rescue craft and in particular the legacy of the Advanced Technology Partnership.

Keywords: RNLI, RNLI ATP, search and rescue craft, lifeboats

1. Introduction

The Royal National Lifeboat Institution (RNLI) has provided a search and rescue service for the UK and Republic of Ireland since 1824, and it is recognised as being one of the leading lifeboat organisations in the world. The RNLI provides a lifeboat service around the coast of the United Kingdom and Ireland 24 hours a day and 365 days a year, along with other prevention and lifesaving activities. The RNLI has a fleet of over 400 lifeboats ranging

*Corresponding Author:
Maritime Engineering, University of Southampton, Boldrewood Campus, Burgess Road, Southampton, SO16 7QF, United Kingdom.
Tel: +44 2380 599544
email: j.i.r.blake@soton.ac.uk

from 4.9m to 17m in length operating from over 230 lifeboat stations. The boats are launched more than 7000 times a year in all weather conditions. The RNLI, as with other search and rescue organisations, is primarily concerned with saving lives. The boats are expected to be the ultimate in marine craft safety designed to withstand the loads likely to be experienced during a service call.

In August 2000, two friends and professional engineering colleagues discussed how to transfer technology advances between their two organisations for those organisations' mutual benefit and for dissemination to the wider scientific and industrial communities. They were passionate that through collaboration and co-operation, industrial innovation could be fast-tracked by supporting cutting edge research and stimulating new areas of academe. These two gentlemen were Bob Cripps, the then Engineering Manager at the RNLI, and Ajit Shenoi, then a senior lecturer in lightweight structures at the University of Southampton. The seeds were sown for what was to later become, following a succession of undergraduate and postgraduate projects and ad hoc consultancy, the Advanced Technology Partnership between the RNLI and the University of Southampton. The ATP was established in 2001 and subsequently flourished, providing a model for applying and disseminating academic knowledge from institutions across the UK and beyond to the mission of saving lives at sea[1].

This paper reviews firstly the relationship between the RNLI and academia before reporting on how the RNLI have specifically engaged with the engineering research community and importantly how the research initiated by the RNLI continues to be cited by researchers across the international community.

2. RNLI publication timeline

To generate a timeline of RNLI scholarly references, Harzing's Publish or Perish was used to collate all 991 articles from Google Scholar that explicitly refer to the *RNLI* and *lifeboat* in online documents. Whilst Web of Science is the standard dataset for bibliometric analysis, it is possible that relevant publications are missed[2]. Google Scholar is a powerful resource to gather online scholarly articles but can index low quality sources and artificially inflate the number of citations[3]. Google Scholar is therefore used to provide a comprehensive timeline of publications, but Web of Science will be used for citation indexing.

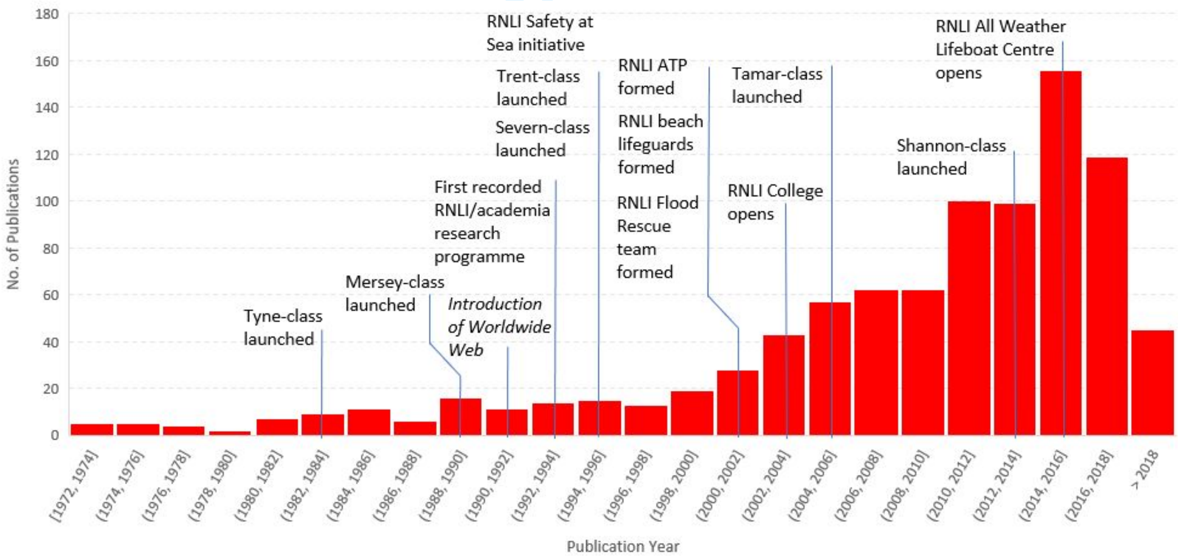

Figure 1 Number of scholarly publications from 1970-2020 identified by *RNLI* and *lifeboat* keyword search using Google Scholar and collated through Harzing's Publish or Perish. Overlaid is a timeline of RNLI key events. 991 publications identified.

Up to the end of 2000, the number of scholarly publications per year were less than 20. Most of these publications were focussed on the RNLI's role and its history as a charitable organisation that exists to save lives at sea.

As the RNLI fleet expanded from the mid 1980's, incorporating the Tyne and Mersey into their fleet by 1990, it was becoming more challenging to meet target displacements with conventional hull materials; lifeboats were getting heavier due to adoption of new technologies and requirements for increased operational range. In 1993, the RNLI partnered the University of Southampton with link funding from the then Department of Trade & Industry and the Science and Engineering Research Council (DTI/SERC Structural Composites Link Programme[4]) to investigate the use of structural composites for future RNLI lifeboats. For the RNLI, this was their first funded research relationship in engineering and initiated international recognition of how their state-of-the-art lifeboats were underpinned by cutting edge research. In 1995 the first production Severn-class lifeboat entered service. This was the first lifeboat designed at the outset to be constructed from advanced polymer composites.

The sharp increase in scholarly publications related to the RNLI and its activities really came from the start of the 2000's, increasing on average by around 7 publications/year until a peak in 2016 of around 120 publications. The rapid increase of publications may be linked to the use of the Worldwide Web from the mid 1990's allowing for more RNLI-related scholarly sources to be stored and accessed electronically. But there are also clear increases and diversification of RNLI activities in the early 2000's including the formation of the beach lifeguard and flood rescue services, both initiating new research areas in academia[5, 6]. The Advanced Technology Partnership at Southampton was also officially started in 2001, consolidating burgeoning academic links in engineering already initiated at Newcastle[7-9] and Southampton[4, 10-12] to support the move to composite lifeboats. In 2010, the RNLI ATP's breadth was expanded to include Southampton's Centre of Operational Research, Management Sciences & Information Systems (CORMSIS). This expansion reflected the RNLI's increasing need to engage management science and operational research in supporting the RNLI's engineering department[13]. By engaging with academia and supporting a programme of PhD scholars through the RNLI ATP at Southampton and more recently with Newcastle and Bristol, dissemination of applied research was secured.

3. RNLI research areas

It is possible to see the nature of these publications, what their focus is and how they are related by using a bibliometric analysis tool, in this case VOSviewer[14]. To facilitate this analysis, a Web of Science search using the terms *RNLI* or *Royal National Lifeboat Institution* allows a more focussed collection of articles, detailing author-supplied and Web of Science-indexed keywords, as well as citation information. The Web of Science core collection covers over 76 million journal articles, conference proceedings, book chapters, notes, reviews and news items. The bibliometric tool, VOSviewer, uses natural language computation to analyse the relationship between the 26 articles found, using in this instance 124 terms identified to have some co-occurrence between articles. VOSviewer generated 14 clusters from the 124 co-occurring terms; clusters in this instance we can interpret as topics. Figure 2 provides a visualisation of the cluster relationships and the links between clusters. Not all terms in a cluster are visible and either the highest linked or a representative term (alphabetically sorted) is visible. The separation of the clusters in the visualisation shows the connection strength between the clusters or topics. Clearly areas relating to social, management and risk, key principles underpinning the RNLI vision and values, have the highest number of publications and the most links.

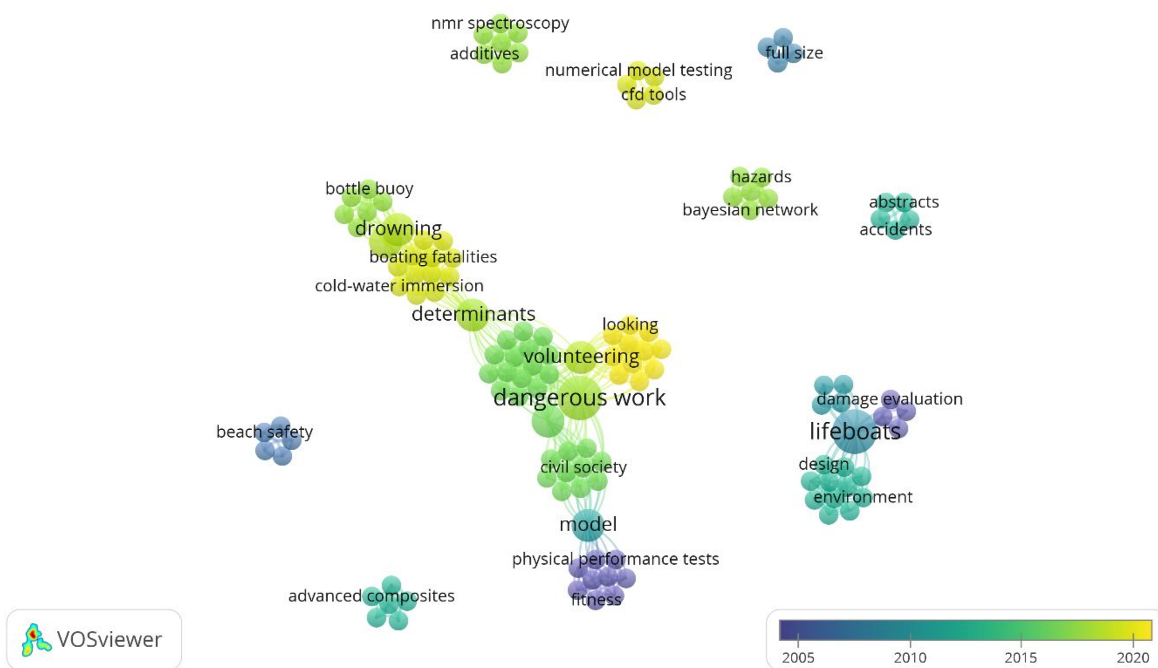

Figure 2 *RNLI or Royal National Lifeboat Institution* keyword in Web of Science core collection publications since 1970. Legend details average year that cluster terms were published.

Table 1 provides more details on the 14 clusters and the co-occurring terms. The most linked clusters seen in Fig 2 are clusters 1-4 and 6, relating to the more social, management and risk terms: human and organisation. Clusters 5 and 7 are highly linked: these tie more to the efficiency and assessment of the most recognisable RNLI engineering asset: the lifeboat. The remaining clusters have no co-occurring terms between them but closer inspection shows they represent scientific investigations into beach safety and accident reporting (clusters 10-12) and four remaining clusters (8, 9, 13 & 14) supporting the engineering assets. The most recent publications centre around cluster 13 with the use of *numerical modelling* and *CFD* and cluster 3 where *dangerous work* is the strongest co-occurring term in publications associated with the RNLI.

Table 1: 14 Clusters made up of 124 co-occurring terms from 26 scientific RNLI-referenced articles from Web of Science since 1970. Terms in bold represent the most highly linked. Dark grey shaded clusters constitute terms associated with RNLI vision and values around the human and organisation; light grey and unshaded clusters constitute terms associated with the RNLI assets: lifeboats, their sustainability and engineering support.

Cluster (# terms)	5 Highest Linked Terms
1 (20 terms)	Bangladesh, boating fatalities, bottle buoy, coast, cold-water, immersion, commercial fishing, curriculum, **determinants**, drowning, fisheries, gulf-of-mexico, jugaad, low-resource, personal flotation device, recreational boaters, responses, safety, sea safety, tutors, weather conditions
2 (14 terms)	Agency, charities, discipline, discourse, emotion, identity work, motivations, not-for-profit organizations, organizations, personality, social-psychology, structure, thick volunteering, volunteerism
3 (13 terms)	Context, **dangerous work**, edgework, looking, management, meaningful work, politics, risk, search, security, solidarity, volunteering
4 (10 terms)	civil society, cultural control, identity, managerialism, non-profit organizations, organizational control, paid work, resistance, **socialization**, voluntary work
5 (11 terms)	Design, economic impact, efficiency, environment, green tribology, performance, recycled plastics, scroll expander, small-scale combined heat and power (chp)
6 (10 terms)	Fitness, fitness standard, fitness test, lifeboat, **model**, physical performance tests, prediction, retirement, selection
7 (9 terms)	composite structures, damage evaluation, friction mechanisms, inspection techniques, **lifeboats**, marine, repairs, stress analysis, wear mechanisms
8 (7 terms)	Additives, analytical ferrography, cylinder liner, marine lubricants, nmr (nuclear magnetic resonance) spectroscopy, spectroscopy, tribology testing
9 (5 terms)	advanced composites, finite element analysis (fea), marine structural adhesives, non destructive evaluation (nde), tee-joints
10 (6 terms)	bayesian network, beach users, hazards, lifeguard, multiple linear regression, rip current
11 (5 terms)	Abstracts, accidents, decompression illness, diving deaths, recreational diving
12 (5 terms)	beach safety, beach type, high energy, macro-tidal, rip currents
13 (5 terms)	CFD tools, experimental fluid dynamics, numerical model testing, towing tank, virtual towing tank
14 (4 terms)	full size, model scale, rigid inflatable boats, seakeeping

Figure 2 and Table 1 clearly show that as a charity with volunteer lifeboat crews operating in potentially dangerous conditions, they provide rich material for case studies in social and management sciences (83 of 124 terms). But the RNLI also has a wide engagement with the engineering science community through actively supported research, initiated through the RNLI's engineering teams over the years, including Bob Cripps[15-17], Steve Austen[18-20] and Holly Phillips[21-23]. The focus of this research is centred in the UK as indicated by the network of RNLI-associated researchers that have been cited in engineering fora, Figure 3 (Harzing's Publish or Perish and Google Scholar). Using VOSviewer, four principal institutions are reflected by the author affiliations: Bournemouth University, Newcastle University, University of Bristol and the University of Southampton.

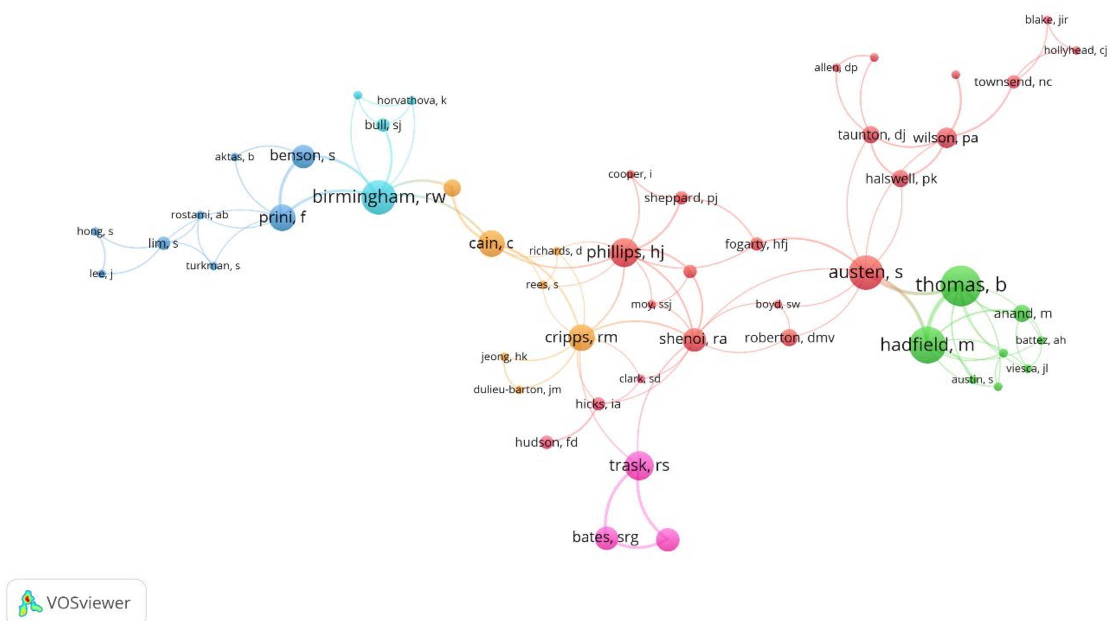

Figure 3 Network of authors: cited engineering texts referencing *RNLI* or *Royal National Lifeboat Institution*. Authors are broadly clustered by institution: University of Southampton (red & orange); Newcastle University (blue); Bournemouth University (green); RNLI (centre red & orange); University of Bristol (pink). Google Scholar search (1970-2020) using Harzing's Publish or Perish. 52 out of 1599 authors are identified and presented based on connection to RNLI engineering staff: Cripps, Austen or Phillips.

By identifying the authors linked to RNLI research, it is possible to see implied institutional strength. Table 2 describes in more detail the 5 highest characteristic terms associated with RNLI-research authors from each institution (ranking is based on 'total link strength', the number of times a term co-occurs between documents in the data set). For the RNLI, Bournemouth University (BU) is used mainly for tribology research. Here, tribology research focussed predominantly on the challenge for the RNLI to better understand the launch slipway interactions with the lifeboats[24] and also on lifeboat engine wear reduction [25-27]. Broadly defining labels for the clusters, Newcastle University (NU) and the University of Southampton (UoS) concentrated predominantly on the lifeboats themselves: Newcastle focussing on RNLI's interests in safety[7, 9], vessel response and load characterisation[28-32], and Southampton on high performance composites[4, 10-12, 33-35], fleet life extension[16, 33, 36, 37] and human factors[38-42]. With Professor Trask having moved from Southampton to the University of Bristol (UoB), the RNLI have broadened their composites research to include more recent developments in 3D printed thermoplastic sandwich cores[43, 44].

Table 2: Perceived institutional strengths based on most cited authors for research undertaken with the RNLI. 5 highest linked terms presented. All publications of authors in engineering science having association with the RNLI have been collated from Web of Science.

Institution	Cluster (# terms)	Terms
University of Bristol	1 (63 terms)	strength; polymer; impact damage; impact; performance
	2 (62 terms)	self-healing; damage; repair; self-repair; system
	3 (53 terms)	delamination; behavior; resistance; design; fracture toughness
	4 (28 terms)	bone; particles; nacre; model; mechanical properties
	5 (28 terms)	origami; hydrogels; actuation; movement; ionoprinting
	6 (19 terms)	shape; thickness; polymers; fabrication; composite morphing
	7 (13 terms)	thermoplastic polyurethane; cellular structures; additive manufacturing; functional grading; foams
	8 (11 terms)	fracture; tibial fractures; strain; stiffness; screw number
	9 (8 terms)	mech-props; comp mats; computed tomography; velocity impact damage; toughened epoxies
	10 (7 terms)	joints; specimens; mechanisms; frp; disbond
Bournemouth University	1 (84 terms)	Friction; wear; ionic liquids; mechanism; steel
	2 (31 terms)	behavior; tribological properties; lubricant additive; lubricant; modified tio2 nanoparticle
	3 (25 terms)	antiwear performance; tribofilm formation; phosphonium; imidazolium; biodegradability
	4 (24 terms)	wear behavior; alloy; resistance; laser cladding; composite
	5 (21 terms)	mechanical-properties; contact; deterioration; solid-state nmr; seizure
	6 (15 terms)	growth; vickers indentation; spherical indentation; solids; simulations
	7 (14 terms)	thermophysical properties; tension; surface free-energy; physical-properties; corrosion
	8 (11 terms)	silicon nitride; surface strength; rolling contact; rolling contact fatigue; residual stress
	9 (10 terms)	sustainability; small-scale chp; scroll expander; recycled plastics; lifeboats
	10 (4 terms)	wear scar diameter; tribotesting; optical profilometry; astm d4172
	11 (3 terms)	surface analysis; spectra; boundary lubrication
Newcastle University	1 (19 terms)	ultimate strength; nonlinear finite element analysis; buckling; progressive collapse; aluminium
	2 (16 terms)	u'water radiated noise; propeller cavitation noise; exp hydrodynamics; research vessel; prediction
	3 (8 terms)	wake simulation; wake screen; tests; streamline tracing; particle image velocimetry (piv)
	4 (7 terms)	model tests; u'water radiated noise; renewable energy; leading-edge tubercle; hydro performance
	5 (5 terms)	spectra; sonic project; propeller cavitation; full scale measurements; correlation method
	6 (5 terms)	cavitation; systematic propeller tests; round robin noise tests; inclined shaft effect; propeller
	7 (3 terms)	propeller cavitation erosion; propeller blade coating; cavitation erosion measurement
	8 (3 terms)	rov; launch & recovery system; hydrodynamic
University of Southampton	1 (91 terms)	behavior; damage; strength; design; delamination
	2 (43 terms)	fatigue; reliability; pitting corrosion; stress; ultimate strength
	3 (41 terms)	composite; digital image correlation; thermography; temperature; optimization
	4 (41 terms)	thermoelastic stress analysis (tsa); spate; composite materials; stress-analysis; calibration
	5 (33 terms)	performance; resistance; systems; bio-inspired; models
	6 (29 terms)	vibration; shells; plates; finite-element; stability
	7 (27 terms)	composites; frp; shear; fiber-reinforced composites; failure criteria
	8 (26 terms)	prediction; simulation; phenomenological models; laminated plates; residual-stress
	9 (23 terms)	flow; part; large-eddy simulation; transition; resin
	10 (22 terms)	model; growth; system; damage mechanics; transverse cracking
	11 (15 terms)	polymer; mechanical properties; digital image correlation (dic); through thickness; thermoplastic
	12 (12 terms)	sea; identification; whole body vibration; system identification (si); support vector machine
	13 (9 terms)	thermoelastic stress-analysis; textile composites; outlier analysis; location; lamb waves

4.RNLI research impact

By tracking the citations of those publications associated with RNLI engineering research, it is possible to determine the impact the RNLI has had on the scientific community and the reach of their engineering influence.

Using Web of Science to collate all identifiable engineering articles written in association with the RNLI (the reference section contains a list of authors), it is possible to see, using VOSviewer, the extent to which those articles have been cited, the publication's relevance and longevity and the citation 'connectivity'. Figure 4 shows the citation connectivity by examining the co-occurrence of terms in the citations' titles, abstracts and keywords (review articles and self citations have been removed). In order to remove the effect of an article's age having had more time to gain citations, VOSviewer non-dimensionalises article citations against the total number of citations for all articles in the dataset for that year in question[14].

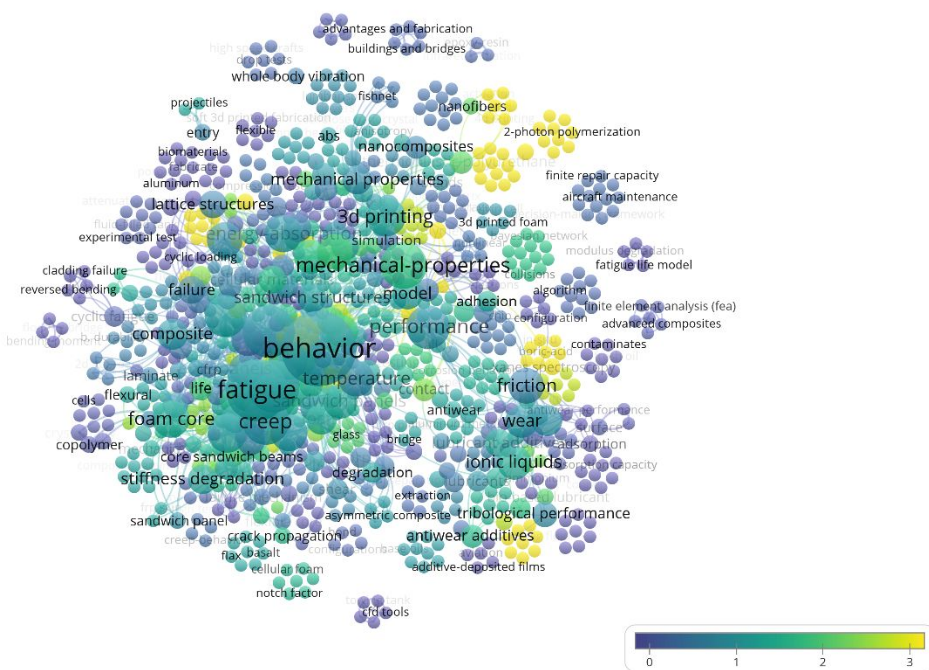

Figure 4 922 co-occurring keywords between all citations of RNLI engineering publications (Web of Science 1970-2020). The focus of international attention very much centres around historic research on sandwich composites, damage tolerance and life prediction methodologies. Legend details a cluster's average number of citations, normalised against age. Bright yellow clusters indicate rapidly developing areas of impact in tribology and additive manufacturing.

The largest academic impact is usually correlated to scientific fields that have obvious cross sector appeal. Many of the citations therefore refer to the RNLI ATP's research on composites, sandwich composites and life prediction methodologies. The yellow clusters indicate that there is a rapidly increasing impact of work undertaken at Bournemouth University in tribology[26, 27, 45], and at the University of Bristol with their recent advances in additive manufacturing (3D printing) as applied to novel energy absorbing sandwich cores [43, 44]. Table 3 provides more detail on the engineering top 10 research areas [46-55] citing RNLI-associated publications (review articles and authors citing their own work are de-selected in order to show the breadth of RNLI impact).

Table 3: Top 10 articles based on normalised-by-age citing of RNLI-associated engineering research undertaken at UoB, BU, NU, UoS and example corresponding research area or term (VOSviewer bibliometrics from Web of Science search of citations of all RNLI-associated engineering authors at UoB, BU, NU and UoS; review papers & self-citations omitted; 1970-2020).

Term	Citing article (**# citations**); and the RNLI-associated article being cited (**# citations**)
chip contact length	Sani, A. S. A., Rahim, E. A., Sharif, S., & Sasahara, H. (2019). *Machining performance of vegetable oil with phosphonium-and ammonium-based ionic liquids via MQL technique*. J Cleaner Prod, 209, 947-964. (**10**); Anand, M, Hadfield, M, Viesca, JL, Thomas, B, Battez, AH, Austen, S (2015), *Ionic liquids as tribological performance improving additive for in-service and used fully-formulated diesel engine lubricants*, Wear, doi:10.1016/j.wear.2015.01.055, 334-5:67-74 (**38**)
crash worthiness design	Yu, X., Pan, L., Chen, J., Zhang, X., & Wei, P. (2019). *Experimental and numerical study on the energy absorption abilities of trabecular–honeycomb biomimetic structures inspired by beetle elytra*. J Mat Sci, 54(3), 2193-2204. (**10**); Bates, S. R., Farrow, I. R., & Trask, R. S. (2016). *3D printed polyurethane honeycombs for repeated tailored energy absorption*. Materials & Design, 112, 172-183. (**45**)
LENS[a]	Baranowski, P., Płatek, P., Antolak-Dudka, A., Sarzyński, M., Kucewicz, M., Durejko, T. & Czujko, T. (2019). *Deformation of honeycomb cellular structures manufactured with Laser Engineered Net Shaping (LENS) technology under quasi-static loading: Experimental testing and simulation*. Additive Manufacturing, 25, 307-316. (**10**); Bates, S. R., Farrow, I. R., & Trask, R. S. (2016). 3D printed polyurethane honeycombs for repeated tailored energy absorption. Materials & Design, 112, 172-183. (45)
collapse mechanisms	Sharma, N, Gibson, RF & Ayorinde, EO, *Fatigue of Foam and Honeycomb Core Composite Sandwich Structures: A Tutorial*, J Sand Struct, 8(4), pp263-319, 2006 (**38**); Clark, SD, Shenoi, RA & Allen, HG, *Modeling the Fatigue Behavior of Sandwich Beams under Monotonic, 2-step and Block Loading Regimes* , Comp Sci &Tech, 59(4): 471–486, 1999 (**33**)
transverse shear	Jen, Y. M., & Chang, L. Y. (2008). *Evaluating bending fatigue strength of aluminum honeycomb sandwich beams using local parameters*. International Journal of Fatigue, 30(6), 1103-1114. (**33**) Shenoi, RA, Clark SD & Allen, HG, *Fatigue Behaviour of Polymer Composite Sandwich Beams*, J Comp Mat, 29(18), pp2423-2445, 1995 (**40**)
borate esters	Sharma, V., Dörr, N., Erdemir, A., & Aswath, P. B. (2019). *Antiwear properties of binary ashless blend of phosphonium ionic liquids and borate esters in partially formulated oil (No Zn)*. Tribol. Letters, 67(2), 42. (**7**) Anand, M, Hadfield, M, Viesca, JL, Thomas, B, Battez, AH, Austen, S (2015), *Ionic liquids as tribological performance improving additive for in-service and used fully-formulated diesel engine lubricants*, Wear, doi:10.1016/j.wear.2015.01.055, 334-5:67-74 (**38**)
polypropylene	Du, Y., Yan, N., & Kortschot, M. T. (2013). *An experimental study of creep behavior of lightweight natural fiber-reinforced polymer composite/honeycomb core sandwich panels*. Comp Struc, 106, 160-166. (**24**) Shenoi, RA, Allen, HG & Clark SD, *Cyclic creep and creep-fatigue interaction in sandwich beams*, J Strain Anal 32(1), pp1-18, 1997 (**24**)
VARTM[b]	Dai, J., & Hahn, H. T. *Flexural behavior of sandwich beams fabricated by vacuum-assisted resin transfer molding*. Comp Struc ,61(3), 247-253, 2003, (**54**). Clark, SD, Shenoi, RA & Allen, HG, *Modeling the Fatigue Behavior of Sandwich Beams under Monotonic, 2-step and Block Loading Regimes* , Comp Sci &Tech, 59(4): 471–486, 1999 (**33**)
composed creep model	Garrido, M., Correia, J. R., Branco, F. A., & Keller, T. (2014). *Creep behaviour of sandwich panels with rigid polyurethane foam core and glass-fibre reinforced polymer faces: Experimental tests and analytical modelling*. J Comp Mat, 48(18), 2237-2249. (**18**); Shenoi, RA, Allen, HG & Clark SD, *Cyclic creep and creep-fatigue interaction in sandwich beams*, J Strain Anal 32(1), pp1-18, 1997 (**24**)
composite sandwich	Chemami, A., Bey, K., Gilgert, J., & Azari, Z. (2012). *Behaviour of composite sandwich foam-laminated glass/epoxy under solicitation static and fatigue*. Comp Part B, 43(3), 1178-1184. (**15**) Shenoi, RA, Clark SD & Allen, HG, *Fatigue Behaviour of Polymer Composite Sandwich Beams*, J Comp Mat, 29(18), pp2423-2445, 1995 (**40**)

[a]Laser Engineered Net Shaping; [b]Vacuum Assisted Resin Transfer Moulding

Table 3 highlights two points: Ajit Shenoi and co-workers author most of the top cited publications associated with RNLI engineering research[10-12]. This clearly emphasises the importance of the early desire of Bob Cripps and Ajit Shenoi to undertake research for the benefit of the RNLI and produce research output that would benefit the composites community as a whole. Secondly, the need to understand (sandwich) composite fatigue remains a fertile area of research. With the increasing use of composites across industry sectors in the 1990's, the scientific knowledge then being generated by the RNLI research at Southampton had immediate relevance. After 20 years and a growing confidence built through familiarity of designing and operating a composite fleet, the RNLI's need for fundamental material knowledge evolved into research into the lifeboat by treating it as an integrated system, and research into composites centred instead around strategies for life extension and sustainable assets[19, 20, 56, 57]. The future looks exciting with some of the most recent work in RNLI-associated research in tribology[27] and additive manufacturing[43] already generating considerable impact in the scientific community.

The RNLI has recently published 'Our Watch' [58], its strategic intent up to 2024, and a view to beyond. It is acknowledged that the way the RNLI delivers its lifesaving, water safety and fundraising activities will change over time as technology and methods of communication emerge rapidly. Consequently, it will be vital for the RNLI to maintain and continue its relationship with academia and other industry partners to enable it to meet these challenges now and in the future.

5. Summary

The RNLI's interest in composite engineering for their fleet and the need to understand their lifeboats' condition after being subjected to extremely challenging, persistent and tough environmental loads, finds much resonance with the scientific community looking at similar challenges in sectors from aerospace to renewable energy. It is evident that the scientific community and wider industry benefit from partnerships and collaboration of academia with the RNLI. But if recent research explorations between the RNLI and academia, not just in engineering but across all disciplines, are to create the largest scientific impact, this work must be disseminated through the most wide reaching of scholarly mechanisms. In this way recent trends in the number of scientific publications post 2016 (see Figure 1) can be revitalised. There is an appetite for research outcomes associated with the RNLI, and the open dissemination of this must be assured. This was the original philosophy behind Bob Cripps' and Ajit Shenoi's initiative in advanced technology partnerships, a philosophy of collaboration, collegiality and dissemination. It has had significant impact both for the RNLI and for the institutions and their researchers, present and past, excited by the challenge of engineering lifesaving craft in the maritime environment and it is a legacy that should be cherished. It is fitting also to acknowledge the foresight of the RNLI's founder, Sir William Hillary, who in 1824 understood that new technology could help more people and this vision will no doubt continue well beyond the RNLI's 200th anniversary.

Plate 1. Signing of the Advanced Technology Partnership between the RNLI and the University of Southampton, 2001. From left to right: (back) Prof Ajit Shenoi (UoS), Prof Geraint Price (Head of the School of Engineering Sciences, UoS), Mr Andrew Freemantle (Chief Executive, RNLI), Prof Bob Cripps (RNLI); (front) Mr Peter Nicholson (Chairman of the RNLI), Professor Sir Howard Newby (Vice chancellor at the University of Southampton).

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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References

1. Tate A, Walshe J, Phillips HJ, et al. *A History of the Advanced Technology Partnership (ATP)*. 2016. Southampton, UK: University of Southampton.
2. Aksnes DW and Sivertsen G. A Criteria-based Assessment of the Coverage of Scopus and Web of Science. *Journal of Data and Information Science* 2019; 4: 1-21. DOI: 10.2478/jdis-2019-0001.
3. Delgado López-Cózar E, Robinson-García N and Torres-Salinas D. The Google scholar experiment: How to index false papers and manipulate bibliometric indicators. *J Assoc Inf Sci Tech* 2014; 65: 446-454. DOI: 10.1002/asi.23056.
4. Clark SD, Shenoi RA and Allen HG. *Fatigue characteristics of FRP sandwich beams for marine applications*. Report no. 67, 1993. Southampton, UK: University of Southampton.
5. Austin M, Scott T, Brown J, et al. Temporal observations of rip current circulation on a macro-tidal beach. *Cont Shelf Res* 2010; 30: 1149-1165. DOI: 10.1016/j.csr.2010.03.005.
6. Austin MJ, Scott TM, Russell PE, et al. Rip Current Prediction: Development, Validation, and Evaluation of an Operational Tool. *J Coastal Res* 2013; 29: 283-300. DOI: 10.2112/Jcoastres-D-12-00093.1.
7. Cain CF, Birmingham RW, Sen P, et al. A practical formal safety assessment system for the marine design environment. *Mar Technol Sname N* 1999; 36: 183-193.
8. Bull S, Horvathova K, McNaught R, et al. Friction and Wear of alternative Composite Keels for Slip Launched Lifeboats. *A study for the RNLI* 1999.

9. Birmingham R, Sen P, Cain C, et al. Development and implementation of a design for safety procedure for search and rescue craft. *J Eng Design* 2000; 11: 55-78. DOI: Doi 10.1080/095448200261180.

10. Clark SD, Shenoi RA and Allen HG. Modelling the fatigue behaviour of sandwich beams under monotonic, 2-step and block-loading regimes. *Compos Sci Technol* 1999; 59: 471-486. DOI: Doi 10.1016/S0266-3538(98)00088-8.

11. Shenoi RA, Allen HG and Clark SD. Cyclic creep and creep-fatigue interaction in sandwich beams. *J Strain Anal Eng* 1997; 32: 1-18. DOI: Doi 10.1243/0309324971513175.

12. Shenoi RA, Clark SD and Allen HG. Fatigue behaviour of polymer composite sandwich beams. *J Compos Mater* 1995; 29: 2423-2445. DOI: Doi 10.1177/002199839502901803.

13. Walshe JH, Watson DA, Blake JIR, et al. Through life asset management by integrated life cycle costing and concurrent engineering. *ICCAS 2011: International Conference on Computer Applications in Shipbuilding (19/09/11 - 21/09/11)*. 2011.

14. van Eck NJ and Waltman L. Visualizing Bibliometric Networks. In: Ding Y, Rousseau R and Wolfram D (eds) *Measuring Scholarly Impact: Methods and Practice*. Cham: Springer International Publishing, 2014, pp.285-320.

15. Cripps R, Cain C, Phillips H, et al. Development of a new crew seat for all weather lifeboats. *SURV* 2004; 6: 69-75.

16. Cripps RM. Design and development of lifeboats - Damage evaluation and repair of composite structures. *Appl Mech Mater* 2005; 3-4: 3-8. DOI: DOI 10.4028/www.scientific.net/AMM.3-4.3.

17. Hudson F, Hicks I and Cripps R. The design and development of modern lifeboats. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy* 1993; 207: 3-22.

18. Austen S and Fogarty HFJ. Design and development of a new inflatable lifeboat. *International Journal of Small Craft Technology* 2004. DOI: 10.3940/rina.ijsct.2004.b2.25041.

19. Hollyhead CJ. *Experimental Investigations into the Motions of Vessels, Less Than Twenty Metres in Length, Stationed at Single Point Moorings*. Doctoral, University of Southampton, 2017.

20. Hollyhead CJ, Townsend NC and Blake JIR. Experimental investigations into the current-induced motion of a lifeboat at a single point mooring. *Ocean Eng* 2017; 146: 192-201. DOI: 10.1016/j.oceaneng.2017.09.045.

21. Phillips H. Designing adhesively bonded joints for ship applications. *Woodhead Publ Mater*. Elsevier, 2012, pp.34-45.

22. Phillips H, Fogarty H and Sheppard P. The Development of a High Speed Inshore Lifeboat for the River Thames. *International Journal of Small Craft Technology* 2014. DOI: doi: 10.3940/rina.ijsct.2015.b2.176.

23. Sheppard P, Phillips H, Cooper I, et al. The practical use of NDE methods for the assessment of damaged marine composite structures. In: *Proceedings of ICCM* 2009, pp.27-31.

24. Thomas B, Hadfield M and Austen S. Wear and friction modelling on lifeboat launch slipway panels. *Tribology and Design* 2010: 209-+. DOI: 10.2495/Td100181.

25. Anand M. *A conditional approach to the tribology of RNLI marine systems*. Doctoral, Bournemouth University, 2015.

26. Anand M, Hadfield M, Thomas B, et al. The depletion of ZDDP additives within marine lubricants and associated cylinder liner wear in RNLI lifeboat engines. *P I Mech Eng L-J Mat* 2017; 231: 162-170. DOI: 10.1177/1464420716663235.

27. Anand M, Hadfield M, Viesca JL, et al. Ionic liquids as tribological performance improving additive for in-service and used fully-formulated diesel engine lubricants. *Wear* 2015; 334: 67-74. DOI: 10.1016/j.wear.2015.01.055.

28. Prini F, Benson S, Birmingham RW, et al. Full-scale seakeeping trials of an all-weather lifeboat. Royal Institution of Naval Architects, 2018.

29. Prini F, Benson S, Birmingham R, et al. Seakeeping analysis of a high-speed search and rescue craft by linear potential theory. In: *International Conference on Lightweight Design of Marine Structures, Glasgow, UK* 2015, pp.87-96.

30. Prini F, Birmingham R, Benson S, et al. Enhanced structural design and operation of search and rescue craft. In: *Marine Design XIII, Volume 1: Proceedings of the 13th International Marine Design Conference (IMDC 2018), June 10-14, 2018, Helsinki, Finland* 2018, p.439. CRC Press.

31. Prini F, Birmingham R, Benson S, et al. Motions and loads of a high-speed craft in regular waves: prediction and analysis. In: *24th International HISWA Symposium on Yacht Design and Yacht Construction, Amsterdam, NL* 2016, pp.1-14.

32. Lim S, Turkman S, Rostami AB, et al. Ship performance-using the real world as a laboratory. In: *Full Scale Ship Performance Conference* 2018, Newcastle University.

33. Cripps R, Dulieu-Barton J, Jeong H, et al. A generic methodology for postdamage decisions. *Journal of ship production* 2006; 22: 21-32.

34. Cutter P, Shenoi R and Phillips H. Thermal and Mechanical Response of Sandwich Panels in Fire. *Experimental Analysis of Nano and Engineering Materials and Structures*. Springer, 2007, pp.763-764.

35. Trask R, Cripps B and Shenoi A. Damage tolerance assessment of repaired composite sandwich structures. *Sandwich Structures7: Advancing with Sandwich Structures and Materials* 2005: 507-516. DOI: Doi 10.1007/1-4020-3848-8_51.

36. Roberton DMV. *Life extension of composite structures with application to all weather lifeboats*. Doctoral, University of Southampton, 2015.

37. Roberton D, Shenoi R, Boyd S, et al. A plausible method for fatigue life prediction of boats in a data scarce environment. 2009.

38. Coe T, Xing JT and Shenoi RA. A human body model for dynamic response analysis of an integrated human-seat-controller-high speed marine craft interaction system. Institute of Sound and Vibration Research, 2006.

39. Halswell P, Wilson PA, Taunton DJ, et al. Hydroelastic inflatable boats: relevant literature and new design considerations. *International Journal of Small Craft Technology* 2012.

40. Allen D, Taunton D and Allen R. A study of shock impacts and vibration dose values onboard highspeed marine craft. *Transactions of the Royal Institution of Naval Architects Part A: International Journal of Maritime Engineering* 2008; 150: 1-10.

41. Halswell P. *The vibrations of a flexible planing craft: hydroelasticity, boat motion and noise*. Doctoral, University of Southampton, 2015.

42. Halswell PK, Wilson PA, Taunton DJ, et al. An experimental investigation into whole body vibration generated during the hydroelastic slamming of a high speed craft. *Ocean Eng* 2016; 126: 115-128. DOI: 10.1016/j.oceaneng.2016.09.002.

43. Bates SRG, Farrow IR and Trask RS. 3D printed polyurethane honeycombs for repeated tailored energy absorption. *Mater Design* 2016; 112: 172-183. DOI: 10.1016/j.matdes.2016.08.062.

44. Bates SRG, Farrow IR and Trask RS. Compressive behaviour of 3D printed thermoplastic polyurethane honeycombs with graded densities. *Mater Design* 2019; 162: 130-142. DOI: https://doi.org/10.1016/j.matdes.2018.11.019.

45. Tzanakis I, Hadfield M, Thomas B, et al. Future perspectives on sustainable tribology. *Renew Sust Energ Rev* 2012; 16: 4126-4140. DOI: 10.1016/j.rser.2012.02.064.

46. Baranowski P, Platek P, Antolak-Dudka A, et al. Deformation of honeycomb cellular structures manufactured with Laser Engineered Net Shaping (LENS) technology under quasi-static loading: Experimental testing and simulation. *Addit Manuf* 2019; 25: 307-316. DOI: 10.1016/j.addma.2018.11.018.

47. Chemami A, Bey K, Gilgert J, et al. Behaviour of composite sandwich foam-laminated glass/epoxy under solicitation static and fatigue. *Compos Part B-Eng* 2012; 43: 1178-1184. DOI: 10.1016/j.compositesb.2011.11.051.

48. Dai J and Hahn HT. Flexural behavior of sandwich beams fabricated by vacuum-assisted resin transfer molding. *Compos Struct* 2003; 61: 247-253. DOI: 10.1016/S0263-8223(03)00040-0.
49. Du YC, Yan N and Kortschot MT. An experimental study of creep behavior of lightweight natural fiber-reinforced polymer composite/honeycomb core sandwich panels. *Compos Struct* 2013; 106: 160-166. DOI: 10.1016/j.compstruct.2013.06.007.
50. Garrido M, Correia JR, Branco FA, et al. Creep behaviour of sandwich panels with rigid polyurethane foam core and glass-fibre reinforced polymer faces: Experimental tests and analytical modelling. *J Compos Mater* 2014; 48: 2237-2249. DOI: 10.1177/0021998313496593.
51. Jen YM and Chang LY. Evaluating bending fatigue strength of aluminum honeycomb sandwich beams using local parameters. *Int J Fatigue* 2008; 30: 1103-1114. DOI: 10.1016/j.ijfatigue.2007.08.006.
52. Sani ASA, Abd Rahim E, Sharif S, et al. Machining performance of vegetable oil with phosphonium- and ammonium-based ionic liquids via MQL technique. *J Clean Prod* 2019; 209: 947-964. DOI: 10.1016/j.jclepro.2018.10.317.
53. Sharma N, Gibson RF and Ayorinde EO. Fatigue of foam and honeycomb core composite sandwich structures: A tutorial. *J Sandw Struct Mater* 2006; 8: 263-319. DOI: 10.1177/1099636206063337.
54. Sharma V, Dorr N, Erdemir A, et al. Antiwear Properties of Binary Ashless Blend of Phosphonium Ionic Liquids and Borate Esters in Partially Formulated Oil (No Zn). *Tribol Lett* 2019; 67. DOI: ARTN 42

10.1007/s11249-019-1152-0.
55. Yu XD, Pan LC, Chen JX, et al. Experimental and numerical study on the energy absorption abilities of trabecular-honeycomb biomimetic structures inspired by beetle elytra. *J Mater Sci* 2019; 54: 2193-2204. DOI: 10.1007/s10853-018-2958-0.
56. Otheguy M, Gibson A, Findon E, et al. Repair technology for thermoplastic composite boats. In: *17th international conference on composite materials* 2009.

57. Otheguy M, Gibson A, Findon E, et al. Towards fully recyclable composite craft. In: *Royal Institution of Naval Architects International Conference: Surveillance, Search and Rescue Craft (SURV7)* 2009, Newcastle University.

58. RNLI. Our Watch: Medium-term goals, https://rnli.org/about-us/our-strategy/our-watch-medium-term-goals (2020).