Institution: University College London

Unit of Assessment: 12 – Aeronautical, Mechanical, Chemical and Manufacturing Engineering

Title of case study: Research into trimaran hullforms exploited in novel ship designs by commercial and naval shipping

1. Summary of the impact

A number of trimaran ocean-going ships, based on original designs conceived by UCL researchers, are currently in use. *RV Triton*, the demonstrator trimaran, is presently employed as a patrol vessel to provide Australian Customs and Border Protection with increased capability and lower fuel consumption compared to a monohull. The *Independence Class* of littoral combat ships currently entering service in the US Navy offers improved military capability and one-third lower fuel consumption, with the ensuing benefit of creating almost 2,000 jobs at the shipbuilder, Austal. Similarly, trimaran ferries with their inherent stability have improved passenger comfort and their reduced fuel consumption has lowered operating costs.

2. Underpinning research

Research at UCL into trimaran hullforms for ocean-going ships was initially stimulated through examining trimaran performance in smaller vessels, notably yachts e.g. America's Cup and powerboats e.g. *Ilan Voyager*, which won the coveted 'Round Britain Speed Boat' record in 1990. UCL developed the ocean-going trimaran ship concept and led research activities in this field from initial concept through design, computational and experimental research and analysis of ship trials, along with contributions to a Classification Societies Ship Design Rules.

The university received its first funding for this work in 1993 and the first study of trimaran ship design demonstrated real advantages over monohull ships in the areas of layout, survivability and powering. The trimaran consists of three parallel slim hullforms joined using a cross-deck structure rather than a single wider monohull. Research at UCL demonstrated, through a series of computational and experimental research studies, that the trimaran hullform offers lower resistance at high speeds and a wide deck area. Further ship research had a specific focus on exploring naval architectural characteristics of the configuration, such as stability and roll characteristics [1]. The concept was then taken up in the UK Ministry of Defence (MoD) with a major design study that involved an extensive programme of experimental and design research centring on a scaled 6-metre trimaran model of a 3,000-tonne destroyer, designed at UCL and tested at the Haslar Towing Tank (see references included in [2]). The results of this experimental research work were considered sufficiently promising for the Defence Evaluation and Research Agency (DERA) to build an ocean-going two-thirds-scale Trimaran Technology Demonstrator. The demonstrator, named *Research Vessel Triton*, was principally built to de-risk the structural design. However, it was heavily instrumented to provide data on motions and sea-keeping performance too. Ultimately it was critical to the procurement process considering whether the new trimaran configuration could provide better value for money than the conventional monohull for the Royal Navy's Future Surface Combatant.

RV Triton was built by Vosper Thornycroft, Southampton, UK in 1998 and accepted in 2000 when it commenced an extensive series of trials for design and operational performance, e.g. sea-keeping and helicopter operations. The project included UCL evaluation to compare actual and predicted performance and substantial US Navy involvement such as to monitor structural bending [3]. Also around this period research was undertaken at UCL to explore the challenges of marine engineering the trimaran hullform. High-power propulsion plants are needed for trimarans and whilst these are straightforward to fit into wider-bodied monohulls, the trimaran's narrower centrehull makes installing these a far more challenging issue, if the advantage of increased efficiency offered by the slimmer hullforms is not to be compromised [4].

To initially size a trimaran vessel at the start of preliminary design, it is necessary to determine practically all the principal form parameters. Once the form parameters have been obtained the designer can be reasonably confident that the initial default hull parameter values will only need refining beyond the initial sizing. The degree of that commitment differs substantially from monohull vessels, where it is possible to delay full parametric selection because there is a large historical database upon which to draw information. UCL has published a comprehensive description of the

preliminary design of a trimaran vessel i.e. the 5000-tonne Trimaran Destroyer, for which the DERA Haslar 6m model tests were conducted [2].

Further work in trimaran research was funded through an Office of Naval Research (ONR) initiative. *The Atlantic Center for the Innovative Design and Control of Ships* (ACCeSS) was founded in 2002 to establish an academic environment where engineering disciplines associated with novel hull design and ship automation could be brought together within the context of the total ship system architecture. The academic partners in ACCeSS (http://www.stevens.edu/access) are many USA universities, UCL (the only UK partner) and industry. Importantly, the partners include the Davidson (High Speed Tow Tank) Laboratory and US Naval Academy (Large Tow Tank), Annapolis. The consortium worked with NSWC Carderock on the design, testing and technology development for trimaran hullforms. As part of ACCeSS research activities further research was undertaken on two trimaran models – one large and one small. Specific areas of research addressed were parametric resonance (the interaction of waves with hullform) and side-hull positioning i.e. the relative location of the smaller sidehulls to the centre hullform. The findings were passed into ONR to support US naval interest in trimarans, which was gathering pace with the building of the littoral combat ship. Collaborative research was carried out in several areas, with UCL primarily involved with trimaran resistance characterisation obtained through experimentation in tow tanks, stability analysis including parametric roll and the development of design tools for comparative analysis [5] and [6].

To assist with the work undertaken in the USA, ONR supported sabbaticals (Drs Greig and Bucknall) at the Davidson Laboratory and through an EPSRC award 'Trimaran Resistance Studies' for Visiting Researcher at UCL (Prof R. Royce, Webb Institute) and later a Royal Academy of Engineering (RAE) Global Research Award to Dr T.P. McDonald.

Key researchers

Professor David Andrews – Professor of Naval Architecture 1993-98 (subsequently Professor of Engineering Design 2000 to date)
Professor Richard Bucknall – Professor of Marine Systems 1995-present
Professor Douglas Pattison – Professor of Naval Architecture 1989-93
Dr Alistair Greig – Senior Lecturer 1987 - present
Dr J W Zhang - Lecturer (deceased), 1996-2004
Dr T.P. McDonald - Post-doctoral Researcher 2010-12
Dr T Grafton – Research Assistant 2003-2007

3. References to the research

References [1], [2] and [5] best indicate research quality.

[1] Pattison, D.R. and Zhang, J.W.; 'Trimaran Ships' Transactions RINA, Vol 137. (1995). Available on request.
[2] Andrews D.J.; Chapter 46 'Multihulls', Ship Design and Construction (Ed. T. Lamb) SNAME, New Jersey. (2004). Available on request. Volume II: ISBN-13: 9780939773411
[3] Greig, A.R. and Bucknall, RWG; 'Marine engineering the Trimaran hull form - Opportunities and constraints'. Proceedings of the IMarEST vol 110 (3), p. 181 - 193. (1998). Available on request.
[4] Royce, R; Jianjun, Q; Waters, J; Bucknall, RWG; Greig, A; Smith, T.; 'Facility Comparison on Model Calm Water Resistance Characteristics of the Trimaran'. American Tow Tank Conference, Washington, (2010). Available on request.
[5] McDonald, T.P.; Rusling, S; Greig, A.R.; Bucknall, R; 'A Comparative Study of the US Navy Littoral Combat Ship', Proceedings RINA Intl. Conf. Design and Operation of Trimaran Ships, London (2004). Available on request.
[6] McDonald T.P; Bucknall R.W.G and Greig A.R. 'Comparing Trimaran Small Waterplane Area Center Hull (TriSWACH), Monohull and Trimaran Hullforms: Some Initial Results', Journal of Ship Production and Design, Vol 29 No 4 (2013). http://doi.org/p3b

The ongoing design challenges and applications for trimaran research have been met with

continuous support from industry (MOD (FBG) 2002, US Office of Naval Research 2003 ($58k), TMC LNK SSA 2003 £110k, MOD (NDP) 2009 £7k, MOD DESH/EPSRC CASE 2010 (£89k), ACCeSS 1 Funding from ONR ($390k), ACCeSS 2 Funding from ONR (£200k), together with EPSRC (EP/G033846/1) and RAE travel grants.

4. Details of the impact

The global impact of research undertaken in trimaran ships by the Marine Research Group at UCL over the past 20 years, which influenced Classification Design Rules for Trimaran Ships, can be identified in the period 2008-13 by considering how RV Triton has been adopted as a tropical patrol vessel and the building of new trimaran ships, notably the *Independence Class* of littoral combat ships for the US Navy [f] and the introduction of a new trimaran-variant car ferry.

As described in Section 2, initial research into ocean-going trimaran vessels was undertaken at UCL with a focus on structure, form, seakeeping, resistance, and propulsion arrangements. This led to the building of a research vessel *RV Triton,* which was sold in 2002 after having completed extensive trials. Over the past 5+ years it has been used by the Australian Customs and Border Protection Service (ACBP) as a coastal patrol and fisheries protection vessel on the northern tropical coast of Australia. ACV Triton was refitted with additional accommodation, a more powerful propulsion plant, and a command and control centre which was easily facilitated within its trimaran hullform, which itself remained unchanged. Triton was selected over alternative equivalent monohull vessels for the patrol role because the trimaran hullform that UCL designed offers lower resistance, improved sea-keeping and improved larger upper deck area, which enhances operational capability. These advantages manifest themselves in achieving a superior range and improved fuel economy resulting from its inherently lower resistance; higher operating speeds which is important to the ACBP since the ships are used to catch smugglers; and its large working deck area which allows for multiple operations of helicopters and boats. Overall, the impact of using a trimaran in this role has provided enhanced capability at lower fuel consumption and reduced emissions over similar sized monohull or catamaran vessels [a].

At the end of the Cold War the US Navy determined a need for new ship types to combat asymmetrical littoral (close to shore) threats and the littoral combat ship (LCS) concept was born. In 2010, Austal's *USS Independence* was the first modular high-speed trimaran LCS to be commissioned into the US Navy; this was followed in 2012 by *USS Coronado,* a second trimaran vessel of similar design that completed trials in August 2013. Four more trimaran *Independence Class* vessels have been ordered since 2008, including *USS Jackson*, construction of which began in 2012 [d], and eventually a fleet of 20+ LCS trimaran vessels are expected [b]. An important economic benefit of the trimaran LCS programme has been to support jobs at Austal in Alabama, USA, which has been able to double its workforce to 3,800 [e]. In 2010, the Navy awarded Austal a $432-million contract to build a trimaran LCS, with a further $681-million contract for two more ships awarded in March 2013 [b, c].

The trimaran *Independence Class* LCS design has been tested thoroughly by the US Navy and shown to provide significant benefits to naval operations, including the largest usable payload volume per tonne of ship displacement of all US Navy surface combatants, a large flight deck that has facilitated near simultaneous operation of two helicopters and proven capability of operating the large H-53 helicopter, and operations of multiple unmanned vehicles for reconnaissance and warfare operations. The increased stability of the trimaran hullform has improved flight operations by allowing them to be achieved in higher sea-states than equivalent-sized monohulls and catamarans. Other operational benefits result from the ability of the trimaran configuration to effectively decouple the resistance/powering from the stability relative to an equivalent monohull which can yield a reduction in resistance at higher speeds. The subsequent reduction in the vessel's full-speed power requirements allows a corresponding reduction of around one-third in both fuel consumption and associated emissions [c]. Chief of Naval Operations Adm. Gary Roughead praised the Navy's plan to add both ship designs to the fleet [2010]: *"The LCS is uniquely designed to win against 21st century threats in coastal waters posed by increasingly capable submarines, mines and swarming small craft. Both designs provide the capabilities our Navy needs, and each offers unique features that will provide fleet commanders with a high level of flexibility in employing these ships."* [c]

The trimaran concept is also useful for commercial vessels: the trimaran ferry *Benchijigua Express* entered service in 2005 and has been successfully used to carry cars and passengers between the Canary Islands throughout the REF impact period. The design of the ferry, also built by Austal, draws on the experimental results UCL obtained from its role in the development of RV Triton [h]. In common with other trimaran designs, the reduced resistance resulting from its three slender hullforms means the ferry uses much less fuel at its high speed (40+ knot operation) when compared to an equivalent-sized catarmaran or monohull, which confers an important advantage in the competitive ferry market [i]. *Benchijigua Express* ferry's improved stability also ensures a softer roll, enhancing passenger comfort. *Auto-Express*, the second generation of trimaran passenger ferries launched in 2012, offers further benefits still. The improved design has resulted in an increased waterline length providing improved internal volume and a speed of 39 knots [g]. According to the Head of Research and Development at Austal: "*The trimaran offers greater speed for the same cargo weight and the same power compared to a monohull and a catamaran. It's got better passenger comfort, by which I mean less sea-sickness. It's got a better sea-keeping ability – able to operate in higher sea states… The power consumption is reduced about 20% when operating in a seaway compared to a catamaran…and reduced by as much as 50% when compared with a monohull operating in waves…" [g].*

The rules governing the design of ships (naval and commercial) are predominantly the responsibility of national Classification Societies such as Lloyds Register (LR) for UK. New Classification Society Rules for Trimaran Ships were developed in 2004, with UCL involvement and drawing on expertise developed during the research described in Section 2. Since 2008, the Marine Research Group at UCL has been assisting LR with the approval of new rules governing naval vessel designs including structure and propulsion, thereby providing the foundations that enable ship builders to offer trimaran ships to their customers. Transfer of specialist advice based on our research has been effected via Professor Bucknall's provision of expertise into the LR Naval Rules Technical Committee, of which he is a member [i].

5. Sources to corroborate the impact

[a] Benefits of RV Triton to Australian Customs and Border Protection Service: www.customs.gov.au/webdata/resources/files/NorthernPatrolVessel-ACVTriton.pdf

[b] Award of $681-million contract to Austal http://gcaptain.com/us-navy-awards-four-new-lcs-contracts/

[c] Quote from Chief of Naval Operations on how the LCS meets the Navy's needs, and $432-million contract award: http://gcaptain.com/littoral-combat-ship-contract/

[d] Corroborates orders of *Independence Class* LCS: www.naval-technology.com/projects/littoral/

[e] Doubling of Austal's US workforce: http://gcaptain.com/navy-places-order-austal/

[f] Senior Project Manager, Office of Naval Research, USA, can corroborate that UCL's research contribution and specifically the work of the ACCeSS group has contributed to the wider knowledge base that has enabled the development of the trimaran LCS warships. Contact details provided separately.

[g] Quote from Austal about benefits of trimaran ferry: http://bit.ly/GCOYvA

[h] Confirmation that Austal's ferry development drew on UCL's results from RV Triton in "Coming soon to a port near you: the 126m Trimaran", The Naval Architect p78, September 2004. Available on request.

[i] Technical Director of Austal, Australia can confirm UCL's trimaran's research has contributed to the development of the commercial ferries and the benefits thereof. Contact details provided separately.

[j] Head of Strategic Research and Technology Policy, Lloyds Register, UK, can corroborate UCL's ongoing involvement with developing design rules. Contact details provided separately.