From a childhood in Lanarkshire, where the biggest stretch of water was the loch in Strathclyde Park, Dr Archie Bethel reflected on the last 12 years in which he helped build the Royal Navy's largest-ever vessels. The two Queen Elizabeth-class aircraft carriers – HMS Queen Elizabeth and HMS Prince of Wales – are the most important warships to be built in the UK since the end of World War 2. “For the next 50 years, they will be the face of the Royal Navy and the flagships of the UK,” Dr Bethel said. Playing a role in the project had been a privilege, he added.

Dr Bethel’s lecture explored the significance of the ships from the perspective of one of the industry partners responsible for designing and delivering them. The project is being delivered by an industry alliance led by BAE Systems, with Babcock joining in 2004. The leading engineering support services organisation, which celebrated its 125th birthday last November, employs 7,000 people across Scotland and in 2016, it had a global revenue of more than £4.8 billion. Dr Bethel was the company's senior representative on the alliance’s management board from 2004 until last summer. In 2005, the year after Babcock joined the project, Rosyth was confirmed as the integration site for the new carriers. It has been transformational for the docks, from which Babcock should continue to provide engineering support to the ships over their 50-year operational life.

Dr Bethel said the Queen Elizabeth carriers represented a step change in capability that will be the centrepiece of a modern Royal Navy designed to meet the threats of the future. Their versatility means they could be used in operations ranging from supporting war efforts to providing humanitarian aid and disaster relief. The ships were designed around three fundamental capabilities: carrier air strike; littoral manoeuvre to provide close support to amphibious operations; and maritime force projection.

The carriers' distinctive twin island design will make them instantly recognisable (the twin islands separate the running of the ship from the flying operations). At £6.2 billion, Dr Bethel said the project has had a major economic impact at a regional and national level. It is estimated that about £3 billion of this has been spent in Scotland, with more than 20 Scottish companies participating in the supply chain.

Design work on one of the UK's largest engineering projects began in 1999. Dr Bethel noted: “The scale and complexity of the programme demonstrates the skills of British industry and the ability to deliver world class capabilities to support our armed forces.” The project was a “once-in-a-lifetime opportunity to be involved in an iconic programme”. Dr Bethel said that more than 10,000 people have participated in the design and build.

The project had its origin in the Strategic Defence Review launched by the new Labour Government in 1997. This began the process of designing and procuring two new aircraft carriers. In 2001, the UK became a partner of the US joint strike fighter programme and the following year, the Ministry of Defence announced that the carriers would operate the short take off and vertical landing (stovl) F35B Lightning. Work on the final design and build strategy for the ships commenced in 2003. The Aircraft Carrier Alliance, including the MoD, BAE Systems and Thales and Babcock, was formed in 2005 to carry out the necessary work. By the end of 2009, Dr Bethel said, construction of the ships had begun around the country.

Then in 2010, the new Conservative–Liberal Democrat Government launched a strategic defence review that concluded only one carrier would be brought into service and it would operate the conventional F35, not the stovl version. Dr Bethel said that 18 months of design and construction
changes followed, only for the MoD to then agree to revert to the original plan. “There was a collective sigh of relief from the alliance,” Dr Bethel said. “But damage had been done to the programme in terms of cost, schedule and reputation.” Contracts were renegotiated and the 2015 strategic defence review confirmed that both carriers would be brought into service.

In July 2014, a major milestone was passed when the Queen visited Rosyth to name the first ship HMN Queen Elizabeth. The following year, the carrier was floated out of its dock and within a few months, assembly work began on HMS Prince of Wales. Later this year, HMS Queen Elizabeth will commence sea trials.

Dr Bethel focused on the alliance, which he described as an innovative partnership founded to transform the way large-scale defence projects are developed and delivered. He noted that it was also recognition that no single company in the UK had the resources to complete the carriers on its own. He said the alliance had been formed to ensure all of the partners took collective responsibility and ownership of the project, ultimately sharing both the risk and the reward.

While each of the alliance’s three industrial partners had clearly defined roles and responsibilities, all stuck to a set of founding principles. As cost overruns were shared by all of the alliance members, Dr Bethel said it was in everyone’s interests to support each other’s operations. Nevertheless, sceptics believed the approach would not work, particularly as the companies normally competed fiercely. “The sceptics were wrong,” Dr Bethel observed, “and the alliance has been regarded as a success.”

Dr Bethel described the Queen Elizabeth class ships:

- 280m long
- 9m draught
- 47m mast-head height
- 65,000 tonne displacement
- Nine decks

The size of the carriers was dictated by the demands of the three basic capabilities outlined previously. The integrated design incorporates the latest advanced technologies in areas such as radar, sonar, communications, weapons and weapons handling, and propulsion.

The ships have been designed to support a wide range of aircraft, including the F35B Lightning, Merlin, Wildcat, Apache and Chinook helicopters and, in future, a range of UAVs or drones. They have an efficient electric propulsion system powered by 110MW from two 36MW Rolls Royce MT30 gas turbines and four Wärtsilä 38 diesel generators. That is enough power, Dr Bethel, observed, for a city the size of Aberdeen.

The innovative weapons handling system, designed and built by Babcock, requires significantly fewer crew than weapons operations in previous ships. It also allows weapons to be stored in the safest areas of the ship. Dr Bethel said the mission system was perhaps the most complex area of the design, integrating navigation and bridge, combat, communications and air traffic control, establishing some of the most advanced capabilities of any warship in the world today.

The ships’ crew of 679 – which goes up to 1,600 when the aircrew are embarked – are catered for in four galleys. There are 471 cabins, 1,611 bunks, 11 chilled water plants, three sewage treatment plants, a cinema and fitness suite on each ship. Handheld navigation devices will help the crew find their way around the 3,000 compartments.

Despite all of the technological innovation, Dr Bethel said the build strategy was perhaps the most unique aspect of the project. The goal was to build blocks of each ship to an advanced stage of fitting at six yards around the UK, ready for integration once they reached Rosyth. “It was a real challenge to design everything in such a way as to facilitate that,” Dr Bethel said. “A major success for our strategy was that significant misalignment at points of integration were extremely rare.”

Babcock had to undertake a major infrastructure upgrade at Rosyth in preparation for the blocks’ arrival, including reprofiling the dock and building foundations for a 1,000-tonne Goliath crane. In itself, this constituted the largest civil engineering project in Scotland until work began on the neighbouring Queensferry Crossing suspension bridge. The bulbous bow was the first block of HMS Queen Elizabeth to be positioned in the dock, with more brought in by barge from around the
UK, according to a strict timetable. Once all of the blocks were fitted together, major pieces of equipment arrived to be installed.

HMS Queen Elizabeth came out of dock in 2014. Its integration and commissioning phase is nearing completion and she is due to start sea trials soon. Then she will sail to Portsmouth and enter her base port for the first time later this year. At that point, HMS Prince of Wales will be formally named and floated out of the dock to begin its own period of integration, commissioning and sea trials. It is scheduled to enter Portsmouth in 2020. Dr Bethel said: “One question I’m often asked is are we sure the carriers will get under the bridges?” He said he was confident they would be fine, although their masts would need to be taken down to get through.

Dr Bethel said the project was ambitious and therefore involved a degree of risk. “These ships are prototypes and very different from anything we have built before,” he said. “The distributed build strategy is complex but has been well managed and successfully implemented.” He said the alliance had proved to be an effective way to bring companies and workforces together and he hopes the approach will be used to deliver future projects. Dr Bethel concluded by paying tribute to his alliance partners, the workforces and trade unions who have delivered the ships. He added: “As engineers, let us take great heart and some major credit for the completion in Scotland of both the Queen Elizabeth and the Queensferry Crossing this year.”

Q & A

Q: Were there any technology or manpower shortages during this particular programme?

A: One of the challenges of this project is that technology is changing all the time. We tried to leave big areas of the design until the last minute because we didn't want it to be obsolete. We already have a large package of upgrades for the Queen Elizabeth in 2023 because of changes in technology. We didn't really struggle for manpower, because this has been a project that people have been desperate to work on.

Q: Apart from the crane, could you tell us more about the Chinese providing a labour force in the dockyard and some materials?

A: The crane was brought from Shanghai and they brought their own people to assemble it, but that was the extent of Chinese employment in the dockyard. Most of the people on this project had to be UK passport holders, which is normal for defence sector work.

Q: Will it ever be possible to do this project again? How will you retain skills over 50 years to do it again?

A: Fifty years is a long time. The main business of Babcock is on the support side, so we will be continuing to develop the skills to keep the ships at sea. One of the challenges for the industry is to build on the legacy of what we've learned from the carriers in a way that will allow the naval sector around the UK to continue to develop.

Q: Did you ever consider using nuclear power for the ships?

A: There was a discussion around nuclear power when it was decided to build the carriers in 1999. The economic cost was probably beyond what the UK could buy. But the other major factor was that we were looking to design a different kind of carrier, where it was not just about power projection. Equally important was flexibility, the ability to work in littoral manoeuvre, to be able to land Royal Marines and equipment and come into areas where nuclear carriers just cannot come into. There are very few ports in the world where you can take nuclear carriers. There was a decision to go conventional with a multi-role carrier that will be much more suited to the operations of the future.
Q: Is it not the case that one nuclear missile could take out such ginormous aircraft carriers?
A: I'm not the expert to talk to about strategy. However, aircraft carriers are pretty difficult to hit. They are well protected: they will have nuclear submarine, frigate and destroyer support to intercept missiles and other weapons fired at the carriers. I don't think they're a big target in the expanse of the ocean. Twelve nations have carriers at the moment but only about four can really use them. You have to have a grade one navy to get them to work.

Q: Has there been some controversy regarding the delivery dates for the aircraft that the carriers will carry?
A: There are two squadrons of F35s already in the US and two Royal Air Force squadrons based out there are training on them. After the Queen Elizabeth has been in Portsmouth a short time, she will go out to the US and be there for most of 2018 being fitted with the stovl version of the F35, so the UK will be the first to deploy them on carriers. We have got eight already and four will be delivered by the end of the summer. By the time the Queen Elizabeth comes back at the end of 2018, we should be up to 16 and will have a full complement of 35 by 2023.

Q: Do you think you should retro-fit the catapult, and what have you done with the space the ski jump would have taken up?
A: The deck configuration changes with the catapult and ski lift – 342 compartments were impacted by the conversion of stovl to catapult [a decision that was reversed after 18 months]. I don't think we will convert it again. One thing in these carriers is that there's no shortage of space. With a crew of only 679 people, there may be some days when you might not bump into anyone at all.

Q: How many women have been working on the construction of these two ships?
A: Not nearly as many as we would have liked. We tried really hard to get girls into the apprentice programmes and serving on the ship; probably 25% of the crew will be female. There has been progress on the design, testing and commissioning side and the number of women involved is increasing, but at nothing like the rate we would like.

Q: You showed us the neat fit between the carrier and the dock. Was that pure coincidence? Did the available facilities have any form of influence on the design of the carriers?
A: They did around the country, but not on the total design. Rosyth has the three biggest docks in the UK, but it was a tight fit. I had this nightmare that there would not be enough water to float the carrier, but it floated perfectly.

Q: I'm intrigued by the structural problems of joining these massive sections together. Do you have to take any special measures to distribute the stresses to make sure the joints are not fatigued?
A: That was a major challenge. There are 34 blocks on each carrier and the crane did a total of 126 lifts, sometimes lifting up to 900 tonnes. So we had to do extensive engineering and a major design effort on every lift. It was well planned out.

The Vote of Thanks was offered by Philip Greenish, Chief Executive of the Royal Academy of Engineering.