Willcox in the 'vomit comet', Nasa's zero-gravity aircraft. Below left: From computer modelling of astronaut collision constraints. Below right: The BWB prototype. Photo: Boeing/Bob Ferguson.

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Aircraft designer and hopeful astronaut

Auckland-born Karen Willcox is taking a sabbatical in her home town from her job as a professor of aeronautics and astronautics at the Massachusetts Institute of Technology on the USA's east coast. She spoke with Jenny Rankine.

Willcox's optimisation work has been one of the forces behind two revolutionary aircraft designs - the unmanned X-48B blended wing body (BWB), and the Silent Aircraft Initiative (SAI) conceptual design that may be flying commercially by 2030.

The Boeing BWB's integration of wings, fuselage, engines and tail makes it 30 percent more fuel efficient than a similar-sized conventional aircraft. The 1/12 scale prototype has a 21-foot wingspan, and is scheduled for remotely-piloted flight tests at the end of the year. The US Air Force says it could be in service within 15 years as a multi-role, long-range military aircraft. The 20-person design group for the Boeing BWB included specialists in aerodynamics, structures, engine, propulsion, weights and control systems as well as optimisation.

The SAI design is also triangular, with engines mounted above the wings to shield noise from the ground. Willcox led the SAI's design and acoustic integration research component.

She also leads an international research effort to cut fuel consumption and carbon emissions in 747-size aircraft, with Boeing, NASA, Purdue and Stanford Universities and MIT. While aircraft contribute about four percent of global human carbon emissions, "it is still important for aircraft to reduce that," she says. "Commercial aircraft operate for up to 30 years, so any reductions we make now will have an impact."

"We are looking at the whole design process and systems integration from aerodynamics to better controls and smart computers to change the way an aircraft uses fuel dramatically. There isn't a single technology to achieve the results we want."

"The kinds of maths students learn in high school is everywhere in this project. At the heart of optimisation are derivatives, which tell us how much change we will see in the aircraft's weight or load if we change some design parameter slightly."

These projects use multi-disciplinary design optimisation (MDO). "We write the design as an optimisation problem: minimise the weight of the aircraft subject to these constraints - for example, that the wings don't break, drag equals thrust, lift equals weight, noise doesn't exceed certain limits on take-off and landing - thousands of constraints."

"We'd set the computer running at night and come back in the morning and it would have a design. We'd take it back to the specialists and there might be something not quite right; we were constantly refining the mathematical definition of the problem. The maths contribution allowed the team to evaluate thousands of designs overnight rather than manually change one element at a time."

"Mathematical methods are having a big impact on design. In aircraft design, safety considerations have meant that aircraft are heavier than they need to be. Statistical methods have the potential to come up with much more efficient systems and better designs. For example, an on-board computer alleviating wind gusts by wiggling the flaps in real time could save building extra structure into the wing to withstand them."

"Mathematics shows up everywhere, including computer models of how astronauts move in space - matrices, geometry, trigonometry, derivatives. All those things I learnt about in school that seemed abstract and not very practical turned out to be very meaningful."

Willcox isn't fascinated just with mathematics; she has applied for the next NASA astronaut intake after just missing out on the last one. After an eight-day immersion interview in March, she was in the shortlist of 40 out of 4,000 who applied, but budget cuts meant only nine were accepted. Applicants are selected for teamwork, ability under pressure, creativity and analytical skills.

Before she had her new baby, Willcox played on the MIT women's rugby team, competed in marathons and ultra-marathons, and climbed rock faces. "I really enjoy the challenge of going somewhere I haven't been before and putting myself far away from safety", she says.

Her sabbatical places her close to two grandmothers for her first child Pieter, and brings her back to the University of Auckland where she studied after Lincoln Heights primary school and St Cuthbert's College. "There's a lot of stochastic optimisation in Engineering Science at the University of Auckland, so it's a good community for the kinds of things I'm learning about."

$$L=\prod_{k=1}^{15}(L_k)^{1/15}$$