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Sustainability within Aotearoa New Zealand's aerospace sector: current state and implications for the future

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ABSTRACT

Aotearoa New Zealand's rapidly growing aerospace sector is still in its infancy, which presents us with the unique opportunity to incorporate sustainability as a key performance parameter from the outset. Through surveys and interviews with key stakeholder groups, we show that currently, the sector largely deprioritises environmental sustainability and compliance with Te Tiriti o Waitangi in favour of economic growth. Actors are not incentivised to consider any aspects of sustainability. While environmental concerns are acknowledged, they are often viewed as technical challenges to overcome by individual companies, rather than global systemic issues that require a collaborative approach. Moreover, the Government's role as a customer, investor and regulator creates a sustainability leadership vacuum, with no clear commitment to quantify or prioritise sustainability within the sector. The results highlight the need for a new approach to balance growth with genuine sustainable development principles using innovative governance models.

Abbreviations: DPMC: Department of the Prime Minister and Cabinet; LCA: life cycle assessments; LCANZ: Life Cycle Association of New Zealand; LEO: low Earth orbit; MBIE: Ministry for Business, Innovation and Employment; NASA: National Aeronautics and Space Administration; NZ: New Zealand; NZSA: New Zealand Space Agency: U.S.: United States (of America)

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Introduction

As of 2023, the global space industry is estimated to be worth $546 billion USD, of which close to 80% is generated from commercial ventures (Space Foundation 2023). 90 nations are actively participating in space operations; 2664 spacecraft were deployed into orbit in 2023. Notably, almost half of the global revenue derives from satellite data, e.g. telecommunications, geospatial imagery and remote sensing (Organisation for Economic Co-operation and Development (OECD) 2022; Space Foundation 2022, 2023). Aotearoa New Zealand is now developing and regulating its own aerospace industry, including launching rockets and satellites, and conducting research in areas such as satellite imagery and remote sensing (Moore et al. 2016; Deloitte Access Economics 2019).

However, there are several sustainability concerns that, if neglected, could pose risks to the future of the domestic aerospace sector and its position in the global industry. Addressing these risks can provide opportunities for novel sustainability initiatives that are grounded in Te Tiriti o Waitangi, and account for environmental, economic, social and cultural impacts (Te Tiriti o Waitangi 1840; Te Puni Kōkiri 2001; O'Sullivan et al. 2021). Identifying these issues, risks and opportunities at this early stage of the sector's development will mitigate long-term negative outcomes and enable policy and funding interventions ahead of time. For this paper, we propose that this requires a qualitative approach comprising engagement with diverse stakeholders.

In this paper, we identify the sustainability issues, risks and opportunities facing Aotearoa Zealand's aerospace industry. These have been derived from our anonymous survey and semi-structured one-on-one interviews of Aotearoa New Zealand's aerospace community. Participants were drawn from economic, environmental, social and cultural domains. The major findings in this paper are issues of inconsistent regulation, resource availability and leadership. Moreover, the sector is siloed, lacking partnership with Tangata Whenua and other societal groups, hindering workforce diversity, talent retention and bi-cultural considerations. These issues present sustainability challenges and opportunities for the future of the aerospace sector.

In this paper, the literature review provides global and domestic context on the aerospace economy, sustainability considerations and issues of responsibility. The methodology section describes the design of the anonymous survey and one-on-one interviews, followed by a discussion of the results and current state of the sector. Finally, limitations of the study and implications for the future of the sector are provided.

Literature review

The New Space economy

As public funding for space activity has reduced since the end of the twentieth century (Cornell 2011), there has been a notable shift towards public-private collaborations (National Aeronautics and Space Administration (NASA) 2012; Pekkanen 2019). This shift signifies the emergence of 'New Space', characterised by increasingly cost-effective, democratised access to space by commercial launch providers such as SpaceX and Rocket Lab USA (Pekkanen 2019).

The revenue generated by the global space industry is predicted to reach $1.8 trillion USD by 2035, driven by the deployment of mega-constellations for broadband internet

connectivity and profitable manufacturing of specialist products in space, e.g. fibre-optic cables and pharmaceuticals (Gormley 2024; World Economic Forum 2024). Many countries are prioritising the development of a national ecosystem for space activities, with increased access to venture capital, growing a specialist space workforce, flexible regulations, as well as sovereign defence capabilities enhanced by a presence in space (European Commission 2023; Low Earth Orbit Science and Technology Interagency Working Group 2023; Department for Science, Innovation and Technology & Ministry of Defence 2024). For example, 45% of all government space budgets in 2023 were allocated for international defence (Space Foundation 2023).

Aotearoa New Zealand's own aerospace ecosystem was catalysed by Rocket Lab USA's commercial activity starting in 2016, closely followed by the formation of New Zealand's Space Agency (NZSA) (Moore et al. 2016; Scott 2022). The NZSA, a unit of the Ministry of Business, Innovation and Employment (MBIE), regulates launch payloads and enables business development opportunities, including increased access to funding for commercial ventures and scientific research. Establishing the NZSA has resulted in a growing national aerospace ecosystem of various actors across space and advanced aviation: start-ups, established companies, educational and research institutions, and special interest groups (Dhopade et al. 2023; MBIE 2023b, 2023d). As of 2022, approximately 230 distinct entities operate in the sector (SpaceBase 2022), and in 2019, they contributed $1.75 billion NZD annually to the economy. This accounts for 0.5% of Aotearoa New Zealand's GDP and 0.27% of the global space economy. Rocket Lab USA alone attracts 1.5% of global New Space investments (Deloitte Access Economics 2019). Future growth is predicted, with MBIE aiming for an annual revenue of $10 billion NZD by 2030 (MBIE 2023d).

Sustainability and aerospace

There is a clear need to distinguish between the benefits of aerospace-enabled data, such as Earth observation for environmental monitoring and resource management, from the environmental footprint of aerospace activity (Varughese et al. 2023). This is referred to as the space sustainability paradox, where the indirect benefits arising from aerospace technologies cannot compensate for the environmental degradation resulting from the sector's activities on and off Earth (Wilson and Vasile 2023). The paradox calls for both benefits and environmental impacts to be accounted for, and a systems level approach to the implementation of any policy design and intervention (Varughese et al. 2023; Wilson and Vasile 2023; Brown et al. 2024; Williams et al. 2024).

Ostensibly, the most pressing environmental impact of aerospace activity is the accumulation of objects in near-Earth orbits from spacecraft and rocket bodies (Lawrence et al. 2022; Miraux 2022). These objects pose a significant threat to spacecraft, continued access to space, and astronomical observations of the night sky (Byers et al. 2022; Lawrence et al. 2022; Nandakumar et al. 2023; Williams et al. 2024). Efforts to optimise collision avoidance and debris removal receive the most attention and resources among space sustainability initiatives (Buchs and Bernauer 2023; Varughese et al. 2023). The Space Sustainability Rating, launched in 2022, aims to incorporate these metrics into an incentive system for global satellite operators and represents a proactive approach to orbital debris mitigation (Space Sustainability Rating 2022).

However, there are more environmental, social and cultural considerations that are of growing concern as commercial aerospace activity increases in scale and diversity (Dhopade and Varughese 2024). For example, the accumulation of alumina and soot particles in the middle and upper atmosphere from rocket launch emissions and re-entry threaten to deplete the ozone layer (Wilson 2019; Brown et al. 2022). Life cycle assessments (LCA) of aerospace missions are important for identifying such risks. They highlight the environmental impacts across every aspect of the design, manufacturing, launch and disposal of components (Wilson 2019; Maury et al. 2020; Dhopade et al. 2023; Jones and Jain 2023). However, the lack of coordination and collection of LCA data among industry stakeholders inhibits the effective application of LCA, leading to unsubstantiated claims of sustainable activity (Wilson and Vasile 2023).

The bi-cultural foundation of Aotearoa New Zealand requires authentic partnerships with Tangata Whenua (people of the land) (Te Puni Kōkiri 2001) and respect for Indigenous cultural and scientific practices involving the night sky (Venkatesan et al. 2020; SATCON2 Community Engagement Working Group 2021; Xanthaki 2024). Many Indigenous groups advocate for the cultural value of space (Matamua 2018; Lee et al. 2020; Neilson and Ćirković 2021). These diverse groups, priorities and knowledge systems highlight the need for a transdisciplinary approach to govern orbital resources and guide the sustainable development of the aerospace sector on Earth (Lee et al. 2020; Palmroth et al. 2021; Varughese et al. 2023).

Work has been ongoing to develop a Māori Aerospace Strategy, as well as increase public awareness of Māori astronomical knowledge and Māori leaders in the aerospace sector (Matamua 2018; Taurapa 2022; MBIE 2022b, 2023a, 2024). There is also a growing consciousness of the cultural appropriation of Māori values into Government policies, corporate strategies and research outputs, instead of a genuine effort to maintain the integrity of Māori knowledge and worldviews for future generations (Watene and Yap 2015; Macfarlane and Macfarlane 2019; Ihirangi 2021; O'Sullivan et al. 2021; Moko-Painting et al. 2023). The absence of this genuine effort among the influential non-Māori actors within the aerospace sector has been criticised during and following the National Space Policy consultation review (Taurapa 2022; MBIE 2023a). More coordination and engagement amongst diverse aerospace stakeholders such as businesses, environmental experts, researchers and Indigenous groups, is required to establish a shared conceptualisation of sustainability (Varughese et al. 2023). This shared understanding can form the basis for tangible actions to address and implement sustainable behaviour in the domestic context.

The politics of growth and responsibility

As the global space industry continues its rapid expansion, arguably, it is critical to share our orbital and terrestrial resources equitably and safely (Lawrence et al. 2022; Wilson and Vasile 2023). The governance of these resources is a geo-political issue that requires international cooperation (UN Committee on the Peaceful Uses of Outer Space 2018). Current international treaties and guidelines acknowledge this issue but are challenging to implement due to a lack of meaningful consequences for actors who violate their terms (Treaty Code 2222 (XXI) 1966; UN Committee on the Peaceful Uses of Outer Space 2018; Global Expert Group on Sustainable Lunar Activities 2022).

The absence of accountability allows nations with structural power to dictate the rules (Morin and Tepper 2023). Structural power refers to the ability of countries to influence the behaviour, decisions and outcomes of other countries through the control of resources, rules and norms (Strange 1990). The mechanisms for control tend to be multinational networks and bi-lateral agreements (Morin and Tepper 2023). The U.S. remains the structural superpower in this respect, due to the diversity of its aerospace eco-system, technical capabilities and multinational networks, to which Aotearoa New Zealand is inextricably linked. The bi-lateral agreement with the U.S. to launch U.S. payloads from Māhia Pensinsula aboard Rocket Lab USA's Electron vehicle is a central component of American influence on Aotearoa New Zealand's commercial aerospace activity (Treaty Code B2016-07 2016).

Domestically, the focus on economic development and defence capabilities enhanced by aerospace technology is expected to continue (MBIE 2023d; NZ Ministry of Defence n.d.), in line with the domestic priorities outlined in the 2023 NZ Aerospace Strategy and National Space Policy (MBIE 2023b, 2023c). The new National-led Government's appointment of a Minister for Space (as of publication this is the Honourable Judith Collins) is a clear signal that growth of the aerospace sector will be on the policy agenda (Beehive 2023; MBIE 2023d). This aligns with the intentions behind similar designations of portfolios within other space-faring nations (Foust 2018; US Government 2024; Government of India n.d.; UAE Government n.d.).

The national strategy and policy documents were drafted in close consultation with the industry to intentionally reflect their priorities. They describe the intention of the NZSA to be both a regulator of the space industry and to assist in developing the sector. Specific to sustainability, the policy document outlines four values: stewardship, responsible innovation, responsible use of space and partnership (MBIE 2023c).

While the documents call for accelerated sector growth, they do not address the source of the investment to set up and sustain this business development, or whether the Government will assist through grants, loans, tax schemes, employment regulations, etc. For instance, space-related technological development in other countries is often co-financed by the government, which helps steer the industry towards the nation's space goals (Hufenbach et al. 2014). It is also unclear in the strategy document if the Government's goal is to maximise local workforce recruitment or whether talent is to be recruited internationally. Both options require Government support through, for example, employment or visa schemes, targeted education, investment and vocational pathways.

Regarding responsibility and leadership for sustainable behaviour, there are no explicit policy approaches or initiatives, signalled by the absence of a working definition of 'sustainability'. Instead, the above national strategy and policy documents refer to supporting collaboration and partnerships, e.g. with aviation, wider industry and space initiatives, to progress their technology ambitions such as clean fuel and integrated use of aerial technologies. It is possible that the NZSA's dual role as both a regulator and sector development agency introduces a conflict of interest between sustainability and economic growth, or places too high a demand on their resources to fulfil both commitments.

The aim of our paper is to help clarify the country's sustainability aspirations in aerospace, by asking the questions:

1. What are the key sustainability issues, risks and opportunities within the sector?
2. Which stakeholder groups are perceived to be responsible for enabling sustainability within the sector?

Methodology

We undertook a survey of Aotearoa New Zealand aerospace businesses and performed one-one-on interviews with a sub-section of participants to address these questions. This study was ethically approved by the University of Auckland Human Participants Ethics Committee on 06/05/2022 (Reference Number UAHPEC24002). The survey and interview questions are provided in our replication package (Bickerton et al. 2024). This research was conducted as part of a scoping study to establish directions for future research. A convergent parallel mixed-methods approach was used for the study (Alele and Malau-Aduli 2023). A survey was used to gauge the current perceptions of sustainability and issues facing the domestic aerospace sector, and in parallel, the semi-structured interviews provided qualitative data on the current state and future vision for the aerospace sector. The survey and interview responses were compared with each other and with a thorough literature review published by the author team (Varughese et al. 2023).

Survey

In 2022, we invited 100 Aotearoa New Zealand aerospace businesses to complete an online survey through Qualtrics (Qualtrics XM 2024). The goal of the survey was to gather information on:

1. current perspectives on sustainability,
2. the most pressing issues facing the sector,
3. support needed to transition to the net-zero carbon future,
4. benefits participants may perceive by improving sustainability within their business, and
5. opportunities to improve sustainability within their business and the wider sector.

These five sections consisted of Likert-type scale questions and optional open-ended questions for the participants to expand on their answers.

A list of businesses was compiled through publicly available online listings of organisations actively engaging with aerospace activity (Aerospace New Zealand n.d.; SpaceBase 2022). A senior or key representative from each business, such as an executive officer, was invited via email to complete the survey. A cross-section of businesses across space and advanced aviation was chosen to address the issues across both subsectors. The businesses were chosen based on the assumed market share of the business and their segment of operation to capture diverse segments of the sector, e.g. manufacturing, launch provision, ancillary data services and university-led research and education. This also enabled us to canvas the geographic variation across the country, since many of the advanced aviation businesses were based on the South Island of New Zealand, while more space businesses were based on the North Island. Demographic

information of their business was collected. Responses were anonymous, and no identifiable information was collected.

The total response rate was 22%, after nine responses were removed for empty data. There was a response attrition rate of 23% throughout the survey. 56.5% of responses were from small businesses (1–20 employees), 13% from medium businesses (50–100 employees) and 30% from large businesses (100 + employees). Approximately 88% of responses were from industry, with the rest from universities active in aerospace research and education. Respondents were generally high in the organisation structure with roles such as managers, directors, chief operating officers and established academic staff. The low response rate may be due to several factors, such as the timing of the survey and the relative novelty of the topic for Aotearoa New Zealand. The timing of the survey in mid-2022 coincided with ongoing consultations for the development of the Government's national aerospace strategy and space policy (MBIE 2023a), which may have deterred participants from industry, who were already involved with the Government's consultation processes.

Interviews

The interviews were designed to gather key individuals' perceptions of the future of the aerospace sector as well as risks and opportunities in the context of sustainable development. The semi-structured interview questions were based on the seven questions method recommended by the Department of the Prime Minister and Cabinet (DPMC) as a futures-thinking technique (DPMC 2021). The questions are part of an intelligence gathering process highlighting strategic issues or policy direction about Aotearoa New Zealand's aerospace sector from a wide range of stakeholders (UK Government Office for Science 2017). Participants were provided with the Brundtland definition of sustainable development for context on the term 'sustainability' in the interview questions: 'meeting the needs of the present without comprising the ability of future generations to meet their own needs' (UN Commission on Sustainable Development 2007). The questions were provided to interviewees in advance, and covered their perceptions of:

- connections between aerospace and sustainability,
- drivers for sustainability within the domestic aerospace sector,
- a vision for a sustainable sector in the future,
- good and bad outcomes for a sustainable aerospace sector, and the signals of these,
- successes from the past or other sectors that the domestic aerospace sector can build on,
- tangible actions that can be taken now in order to achieve a good outcome for the sector.

Interview participants were approached as experts from key organisations relevant to the aerospace sector such as government, industry, and independent consultants, and recruited via personalised email invitations. Potential participants were selected based on their alignment with the three dimensions of sustainable development: environmental, economic, socio-cultural (e.g. local government and Māori practices) (Giddings et al. 2002). Such a transdisciplinary cross-section of perspectives internal and external to

the aerospace sector can reveal unforeseen issues and new opportunities (Palmroth et al. 2021; Varughese et al. 2023). From the 20 personalised email invitations that were sent, one participant refused to participate, and ten agreed to participate. From the ten participants, four were Māori, and six participants were non-Māori. Their expertise spanned across all three dimensions, and all were Aotearoa New Zealand-based.

The interviews were conducted over Zoom in 2022, lasted up to 60 min and were transcribed by two of the co-authors, who are research assistants with experience in qualitative data analysis. Interview durations ranged from 30 to 60 min, with an average of 45 min, depending on whether the responses were prepared in advance. Two interviewers from the research team were present in each of the interviews, and the Zoom sessions were recorded in order to be transcribed. All ten hours of interviews were coded for themes using the Nvivo software (Lumivero n.d.) by the research assistants. The research assistants' disciplinary expertise is in astronomy, public policy and anthropology. The coding and thematic analysis were inductive, and framed around issues, risks and opportunities (Braun and Clarke 2021). We drew from the published literature review by the author team, particularly the influence of worldviews, political agendas and definitions of sustainability on industry and government priorities (Varughese et al. 2023). The interview questions played a role in developing a coding reliability thematic analysis by the coders that was applied across all interviews. For instance, the themes pertaining to regulations, space debris and economic incentives were developed inductively, but influenced by the questions on signals of good and bad outcomes. All themes were then discussed with the author team, along with the review of the literature, and survey data, then categorised as issues, risks and opportunities for the sector. For example, a lack of resources and funding was categorised as a risk to the future of the sector, as it may reduce economic output. Conversely, a lack of sustainability knowledge and skills were categorised as an opportunity for the sector to innovate and capitalise on sustainable practices. The author team is experienced in quantitative and qualitative analysis in multiple disciplines including public policy, aerospace and futures thinking.

Results and discussion

This section discusses themes identified from the survey and interviews.

Survey

The survey highlighted that most sustainability associations were with orbital space debris (90% of respondents) followed by emissions from launches (76%), and climate change (62%), which also aligned with the interviewees' perceptions. Participants

Table 1. Themes identified from survey.

Funding	Staffing	Regulations	Next steps
Lack of funding schemes for projects, student scholarships, post-seed funding, Government support, venture capital	Recruitment, domestic talent, qualified staff, gender diversity	Inconsistencies in international regulations, compliance monitoring, Government regulations	Government: guidance and support on sustainability practices, and incentives for businesses

generally acknowledged that the sector was not performing well with regards to sustainability, and that there was an opportunity to expand sustainability-related knowledge and support in the sector. However, they felt sustainability was not their primary challenge, and that it was a forthcoming issue in the next 20 years. The main themes from the survey data are provided in Table 1.

The themes from the survey data were related to funding, staffing, regulations and guidance on sustainability practices. Access to appropriate funding schemes to enable economic growth was the primary issue. This was followed by access to qualified and experienced professionals to enter the aerospace workforce. Industry respondents felt they lacked domestic talent and had to search overseas, as well as keeping up with the evolving skillsets and training required by the industry. While recruiting qualified staff was a definite issue, the lack of diversity in the workforce also compounded the skills shortage, particularly in terms of gender. For instance, only 14% of Aotearoa New Zealand's engineering workforce comprises women, and is a focus of significant outreach, recruitment and retention efforts (The Diversity Agenda 2023).

The issue of regulations highlighted respondents' concerns about complying to international and domestic regulations – the lack of agility, inconsistencies in compliance monitoring, and introduction of barriers to market-driven activity. In the near-future, survey respondents felt that it is the role of the government to lead sustainability initiatives and provide adequate support for them to participate in or implement these initiatives, e.g. through financial incentives.

Interviews

The interviews provided insight into the future vision for the sector, and the perceived responsibilities of the industry, government and public. These themes are summarised in Table 2.

Key issues

A key issue from the interviews was that the aerospace sector in Aotearoa New Zealand operated as a 'siloed industry' with little interaction with other organisations and public stakeholder groups. Instead of having mutually beneficial connections with related sectors, such as commercial aviation and waste management, the industry was perceived

Table 2. Themes identified from interviews.

Key Issues	Risks	Opportunities
Aerospace as a 'siloed industry' with little interaction with Te Tiriti and other domains	Lack of resources, and political interest/leadership for businesses	Industry: scope for innovation, networking, accountability, transparency
Loss of resources and available space in LEO	Accessibility of data: increasing privatisation of services, data use/open access	Government: political leadership, incentives for businesses, agile regulatory systems, build and model bi-cultural frameworks
International regulation, cooperation, compliance and enforcement	Regulations for social benefits: public safety, space data use & privacy	Public: awareness of activities & benefits, Indigenous knowledges, intergenerational thinking
Alternate fuel sources and emissions	Increasing space debris & emissions	Sustainability: 'as a skill' within organisations

to be isolated by those participating in the sector and by those wanting to participate more actively in the sector.

This silo effect may contribute to the staffing issues highlighted in the survey. Interviewees also highlighted the lack of ethnic diversity in the sector. Māori make up only 2% of the engineering workforce (The Diversity Agenda 2023). Two Māori participants suggested the highly technical nature of the aerospace sector was hindering Māori with diverse, non-technical skillsets from contributing.

A critical aspect of the sector's siloed nature was the absence of meaningful discussions with Māori groups on the governance and planning of the sector, beyond superficial consultation processes (Bhatia 2022; MBIE 2023a). Participants felt there was not enough being done to fulfil the sector's Te Tiriti responsibilities, nor enough awareness of Māori knowledge and practices related to kaitiakitanga (a Māori expression of sustainability). Addressing this would require creating the space for rangatiratanga (Māori leadership), which would enable the practice of kaitiakitanga within the sector in a substantial way. As a result, the sector would be better placed to grow in a socio-culturally and environmentally responsible manner. This view was expressed by six out of the ten interviewees from the socio-cultural and environmental domains.

Since the interviews were conducted, there has been progress on developing the Māori Aerospace Strategy by Māori leaders in space science (Dimitrof 2022; Magrin 2024; P. Harris, personal communication, November 2023), and Māori organisations in the sector, such as Tāwhaki Joint Venture (MBIE 2022b) to detail the sector's Te Tiriti responsibilities. The latter is an example of a partnership approach between the Crown and the Tangata Whenua of Kaitorete, a region of strong cultural significance, native biodiversity and aerospace potential. Tāwhaki governance comprises of representatives of the hapū (subtribe) from the region. However, these Māori-led initiatives remain outliers and their successes could be scaled up through intentional resourcing for wider Māori participation in the sector.

Another key issue from interviewees was the concern regarding available space in Low-Earth Orbit (LEO) due to increased congestion from operational and defunct objects, as well as debris. Space debris, which was the most prominent association with sustainability by survey respondents, was framed by most interviewees from industry, Government and academia as a scientific problem to be solved rather than a systemic one requiring a more holistic approach. Some interviewees explicitly highlighted the need for technological development that was critical for continued industrial activity within the orbital environment, for example, active debris removal technology, as opposed to a source-based or more holistic solution that intervenes before waste is in our environment.

An additional issue was continued access to, and use of, fossil fuels for energy-intensive activity such as manufacturing, orbital launch provision, and propulsion for advanced aviation. Interviewees from the economic domain perceived this issue as a driver for procuring alternate fuels, decarbonisation and electrification of future aerospace flight, as per the quote below. This aligns with the global interest in 'green fuels' which has resulted in significant investment in research and development (Wilson and Neumann 2022).

Some interview participants from the environmental and socio-cultural domains raised the uncertainty associated with the environmental footprint of new technologies

and rapid growth in activities. This contrasted with the survey respondents, who opined that environmental sustainability was not their primary concern, and that it was an issue for the future. LCAs are useful here, as they offer a systems perspective and are widely used in other sectors (Wilson 2019; Maury et al. 2020; Jones and Jain 2023). They provide critical insights on the emissions, waste streams and resource consumption of a given product or service over its life, i.e. 'cradle to grave' (Dhopade et al. 2023). Currently, no aerospace companies engage with the Life Cycle Association of New Zealand (LCANZ), nor have published any LCA case studies, suggesting a skillset gap in environmental sustainability.

Another primary issue highlighted by our interview participants was regulation, which was also prominent in the survey data. Regulation was used as a catch-all term for rules dictating the safe operation of industrial activity, e.g. high-altitude licensing, liability arising from new technologies to the industry and towards the space environment. While there was a clear need for regulation, there was an emphasis on coherence and ensuring that domestic regulation aligned with international and other countries' regulations. This would reduce uncertainty for the industry and allow better planning. For instance, a lack of expertise required to issue launch and high-altitude licenses is a significant barrier for the industry (MBIE 2023d). While some industry interviewees framed regulation as a hindrance, the consensus was a need for cohesive, consistent regulation that could adapt quickly to new technological advancements and be implemented efficiently.

Risks

While the survey respondents' need for a consistent, agile regulatory environment was identified as a key issue for the sector, the interviewees' regulatory concerns extended beyond economic and environmental issues. Their concerns included public safety, space data use and data privacy. Specifically, these concerns related to accessibility of aerospace-enabled data and ensuring that the data environment in Aotearoa New Zealand would remain open access, while addressing Māori data sovereignty issues (Walter et al. 2021). Further, the increasing privatisation of services could result in siloed, inaccessible data and hinder societal benefit. This risk is further amplified through continued bi-lateral launch and funding agreements, involving NASA, private U.S. customers and companies such as Rocket Lab USA (MBIE 2022a). There is a possibility that Aotearoa New Zealand may not be able to enforce its own open access data environment or regulate new sustainability practices if most of its commercial aerospace activity is dictated by the norms of the U.S. space economy.

Another specific regulatory concern was a lack of coherency with international practise regarding space debris. Interviewees emphasised the increased prioritisation of space debris management, codified through international agreements. Non-compliance with these agreements could risk the industry's continued operations in space. This risk was underscored by all survey and interview participants.

Relatedly, another area of concern was the insufficient resources available to businesses to enable growth of the sector, e.g. project funding, scholarships for staffing development, post seed-funding, government financial support and general funding schemes, also highlighted in the survey data. As foreshadowed by the national strategy, there is a gap in funding to maintain the industry beyond the initial steps and start-ups

(MBIE 2023b). Without such targeted, longer-term funding, businesses may not be able to grow beyond the small scale, nor be able to manage or innovate on compliance requirements for environmental sustainability initiatives. To overcome this, industry interviewees described the need for national milestones and more market-driven industrial activity instead of military contracts.

Interviewees from industry perceived that inadequate resourcing stemmed from limited political interest and leadership. They felt that genuine leadership from Government was critical to generate buy-in and support, and to provide mobilisation and direction. Without these components, it was judged that the industry would struggle with disparate goals, remain siloed, and both sustainability and Māori partnerships would remain 'tick-box' exercises. It should be noted that since the survey and interviews were undertaken, The Honourable Judith Collins has been appointed as the newly created Minister of Space (Beehive 2023). A number of small prizes and seed funding for feasibility studies have been announced to aid growth of the sector, as well as streamlining of regulatory approvals (Beehive 2024a, 2024c, 2024d; MBIE 2024; Radio New Zealand 2024). Specific actions related to sustainability have yet to be performed by the Minister.

Opportunities

Interview participants perceived the risks highlighted in the previous section also as spaces for opportunity. Industry participants tended to cite extrinsic factors that may force the sector into action, such as worsening impacts of climate change, accumulation of space debris and international policy rules. For *Government* they saw particular scope for political leadership, incentives for business development, agile regulatory systems, and to build and model bi-cultural frameworks. All of these were seen as requirements for sustainability, not merely in terms of the industry's needs to survive and maintain itself, but also to maintain and foster a sustainable environment. This opportunity aligns with the survey respondents' wishes for Government guidance and support towards sustainability practices.

However, while there is an opportunity to provide businesses with guidance on better sustainability practices, interviewees emphasised that consistent regulations and standards must be established first. The current nascent nature of the aerospace sector combined with Aotearoa New Zealand's poor emissions track record (Ministry of the Environment 2023) may explain why sustainability was not the primary concern for these industry participants, and therefore the feeling that the aerospace sector should not take the lead in promoting sustainability. They perceive the latter as the Government's responsibility.

A role for *industry* was also proposed, as participants from the environmental and socio-cultural domains noted sustainability constraints as drivers for innovation, and for networking between organisations and Māori groups to learn from their practices. This would then allow for accountability within the industry and transparency for sustainability practices. Proposed indicators of success included demonstrated benefits to society arising from better environmental monitoring and more informed, equitable decision-making about climate change action. When prompted for models of success, industry participants cited Rocket Lab USA's market growth and Aotearoa New Zealand's participation in the MethaneSAT environmental mission (Beehive 2024b),

reinforcing the priorities of industry development and maximisation of societal benefits through climate change mitigation.

Meanwhile the *public's* role was framed as an enthusiastic beneficiary of the aerospace activities being undertaken in Aotearoa New Zealand, both in terms of sustainability and wider goals. Government and industry participants saw an opportunity for the public to understand the resulting benefits for them, including climate change monitoring and actionable data. A lack of social license from the public was cited as a negative future outcome for the sector. However, it can be argued that social license requires trust and transparency with the public on environmental compliance, Māori participation and societal benefits. Simply targeting the public as a potential downstream beneficiary may not be sufficient to maintain social license. There is also a gap in quantifying the social and cultural impacts of aerospace activity, particularly of downstream satellite data applications (Tassa 2020; OECD 2022) and Māori data sovereignty (Walter et al. 2021). There is an opportunity to perform impactful case studies on aerospace applications in Aotearoa New Zealand that are transparent and co-designed with communities.

Indigenous knowledges and intergenerational thinking were also considered key opportunities for public engagement with the industry, particularly while the industry is so nascent. Development of a good governance model, that acknowledges Tangata Whenua as the kaitiaki (stewards) of Aotearoa, could enable more organic sustainability initiatives and better employment outcomes for Māori.

To an extent, *sustainability* was also framed as an opportunity: to integrate it into aerospace organisations by cultivating it as a distinct skill within these organisations. Additionally, sustainability was framed as an area of innovation for the industry to differentiate itself internationally, provide global leadership and model best practice. This includes activities such as space traffic management and aerospace engineering to minimise emissions of new aircraft and launch vehicles as well as the associated infrastructure changes to airports and spaceports.

Implications for the future

A key finding identified from the analysis was that sustainability was not a high priority for the sector. Although participants mentioned sustainability issues, most tended to focus on the benefits of aerospace-enabled data to support sustainable development practices on Earth, such as data regarding climate change and new technologies, rather than the impact that the sector might have on the environment. Even the issue of continued access to LEO and space traffic management was framed as an externality that the sector must overcome, or develop technical solutions for, rather than admit any complicity towards. This directly aligns with the issues outlined in the space sustainability paradox and may lead to inaction or unsubstantiated claims of sustainable behaviour (Wilson and Vasile 2023), in addition to continued misalignment with Te Tiriti principles (Te Puni Kōkiri 2001).

Moreover, the industry viewed emissions and the promise of alternate fuel sources as technical problems to solve, rather than envisioning system-wide approaches. This phenomenon is not unique to aerospace. For instance, in the plastics sector, biodegradable plastics have been widely marketed as an eco-friendly option to combat plastics

pollution, without a rigorous LCA. This has led to more microplastic pollution and ecological degradation (Qin et al. 2021). There is a missed opportunity here for the aerospace sector to learn from other sectors and draw on diverse repositories of knowledge to generate more innovative solutions. For instance, there is an opportunity to redesign the sector's high-level governance and decision-making models in partnership with Tangata Whenua.

The current dynamic of Aotearoa New Zealand's aerospace economy, supported by public-private partnerships, presents a second paradox. The New Zealand Government is simultaneously a customer, investor, and regulator of the sector, and is being relied upon for leadership in sustainability. The Government's broad mandate and limited resources has skewed the sector towards economic outcomes rather than sustainability outcomes. This has created a leadership vacuum, where no party (Government, industry, or public) assumes responsibility, nor is equipped with the resources to lead. As sector growth continues against the backdrop of unpredictable effects of climate change, rapid technological developments (Copenhagen Institute of Futures Studies 2023), and continued assertion of structural power by the U.S. through aerospace agreements (Morin and Tepper 2023), the relationship between public and private actors needs to be clarified. Specifically, clarity is required on whose role it is to balance growth and regulations with environmental, social and cultural impacts of industrial activity. Co-leadership can come from all parties in the form of co-designed, whole system approaches to governance, funding, revenue generation, regulation, measuring and mitigating life cycle impacts of the activities. These are reflected in the operation and planning of the Tāwhaki Aerospace National Centre and can set a positive example for other aerospace companies. This would address the space sustainability paradox in a more balanced manner; contrasting the growth-driven mindset that undermines the principles of Te Tiriti and sustainable development to continue business-as-usual. This would also lead to more authentically innovative solutions across the technical, regulatory and political leadership domains.

Limitations of current study

The intention of the study was to capture preliminary themes and patterns to inform future research concepts and methodologies. The low response rate limits further interpretations at this initial stage. Most responses were from the space rather than advanced aviation sector, so it is possible that the survey and interviews may not have fully captured the intertwined nature of the two sectors. Future research can aim to increase total response rates and specifically, response rates from advanced aviation.

Conclusion

This study has highlighted key issues, risks, and opportunities regarding sustainability within Aotearoa New Zealand's aerospace sector. We gathered diverse perspectives from industry, government and environmental experts through surveys and interviews. The domestic aerospace sector faces significant challenges and opportunities regarding sustainability, regulation, resource availability and leadership. The sector operates as a siloed industry, lacking partnership with Tangata Whenua and other societal groups,

hindering workforce diversity, talent retention and bi-cultural considerations. Concerns about space debris and reliance on fossil fuels are frequently cited by the industry as reasons for technological innovation and decarbonisation efforts. Regulatory inconsistencies pose risks to industry growth and open-access data principles. Limited resources and political leadership further exacerbate these challenges. Cohesive, agile regulatory frameworks and sustained funding support are highly sought after by the respondents.

However, these challenges also present opportunities for collaboration and innovation. Government guidance and support can drive sustainability practices and incentivise industry growth, while the industry can take advantage of sustainability constraints for innovation and greater accountability. Public engagement is crucial for building social license and realising societal benefits.

While this study provides valuable insights, its limitations highlight the need for further research and integrative approaches. Ultimately, addressing these challenges and embracing opportunities ensures the long-term sustainability and success of Aotearoa New Zealand's aerospace sector.

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