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Launch Vehicle Noise and Australian Spaceports

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As the global space industry expands, rockets are being launched from a greater number of spaceports with a rapidly increasing cadence. Because of the growth in the number of spaceports, the cadence increase, and efforts at vehicle optimization to reduce weight and cost, noise has the potential to create harmful impacts – from vehicle vibroacoustic loading to expanded environmental footprint. This paper provides a brief overview of current Australian spaceport and launch vehicle development, which involves near-term plans for small-payload orbital launches. Bounds on overall sound power level from these rockets is described, as well as maximum overall sound pressure level using two different models. One of these models, RUMBLE, is used to show maximum predicted levels at the Great Barrier Reef. Eventual refinement and validation of these predictions will aid in assessing potential noise impacts on vehicles, structures, communities, and threatened and endangered species.

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1. INTRODUCTION

The global space industry is rapidly expanding. Rockets are being launched from a greater number of spaceports and a recent exponential increase in annual global orbital launches (see Fig. 1) has surpassed numbers seen during the 1960s' Space Race. While about 75% of rockets are currently launched from the United States and the People's Republic of China, an increasing number of countries are tapping into a global space launch services market projected to reach USD 33.4 billion in 2028.[1] Australia is well-situated for launching payloads to a variety of orbits and multiple spaceports are being expanded, constructed, or planned.[2] The Australian Space Agency was created in 2018 to support the growth of Australia's space industry and the use of space across the broader economy. In Dec 2022, the Australian government prepared a response to its House of Representatives Standing Committee on Industry, Innovation, Science and Resources' report: The Now Frontier: Developing Australia's Space Industry.[3] One of the committee's recommendations, with which the Government agreed in principle, was the following: "The Committee recommends that the Australian Government consider a national launch plan or strategy to support a sovereign capability in Australia including the investment, infrastructure and expertise required. This includes development of policies that preference Australian launch capability to support government space requirements." Of note is that in October 2023, a Technology Safeguards Agreement[4] was signed between the United States and Australian governments, permitting sensitive hardware to be more easily passed between the two countries.

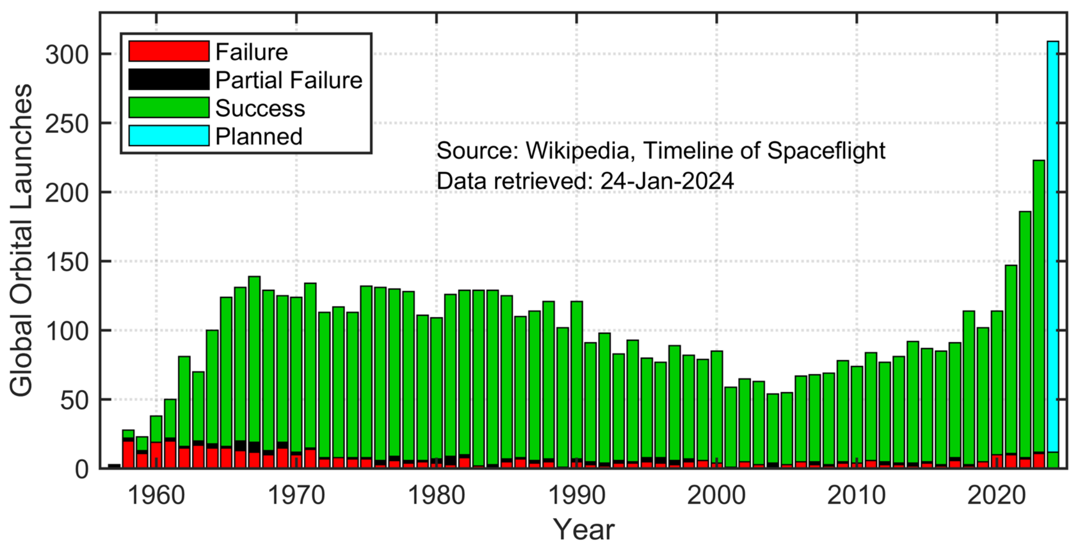

Figure 1. Global orbital launches by year. Data from Wikipedia[5] and Jonathan's Space Report.[6]

Development of policies, infrastructure, and expertise related to spaceports and launch vehicles requires consideration of impacts. One of these impacts is noise. Understanding rocket noise is vital to the design of launch vehicles, payloads, pad and ground facilities, and addressing possible environmental and community noise concerns.[7] In this paper, we review current public information regarding development of Australian orbital launch capabilities and possible noise impacts.

2. AUSTRALIAN SPACEPORTS AND VEHICLES

We first discuss activities at three spaceports with plans for orbital launches. Per recent media reports,[8,9] an additional orbital launch spaceport is planned for Cape York in Far North Queensland. The locations of the three spaceports are shown in Fig. 2. To the north, Arnhem Space Centre,[10] which is operated by Equatorial Launch Australia (ELA), has plans to launch the U.S.-developed Phantom Daytona[11] rocket. In a demonstration of closer ties between United States and Australian interests, ELA recently partnered with NASA for three suborbital launches of Black Branch IX sounding rockets.[12] To the east, Australia's Gilmour Space Technologies is developing the Bowen Orbital Spaceport to launch their Eris orbital rocket.[13] Meanwhile Southern Launch's Whalers Way Orbital Launch Complex[14] is planning to launch Perigree Aerospace's Blue Whale 1[15] rocket. A comparison of basic specifications of these three rockets from information found online is shown in Table I. Nozzle exit diameter has been estimated from photos or drawings, using the vehicle height. Note that engine specific impulse (or plume exit velocity) during liftoff is unknown, but typical exit velocities of liquid-fueled rocket engines are on the order of 2.8 – 3.3 km/s.

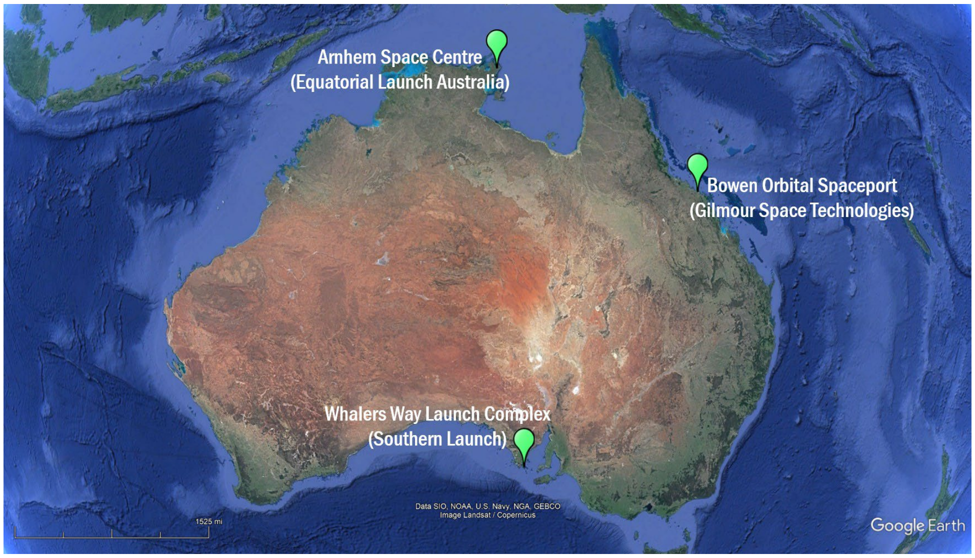

Figure 2. Locations of Australian three launch facilities with planned orbital launches.

Table I. Orbital rockets to be launched from Australian Spaceports

	Daytona	**Blue Whale 1**	**Eris**
Developer (Country Abbrev.)	Phantom (USA)	Perigree (KOR)	Gilmour (AUS)
Planned Launch Complex	Arnhem SC	Whalers Way	Bowen
No. Stages	2	2	3
Height (m)	19	21	25
No. Engines	9	9	4
Engine thrust (kN)	22.2	28.9	114
***Estimated* Nozzle Exit Diameter (m)**	0.3	0.3	0.6
Liftoff Thrust (kN)	200	260	460

As far as orbital rockets are concerned, these vehicles are relatively small. A comparison between the largest of the three, the Gilmour Eris rocket, and the SpaceX Falcon 9 is shown in Fig. 3. The Falcon 9 is 3.3 times taller and generates 16.5 times the liftoff thrust of Eris. That is not to say larger rockets will never launch from Australian spaceports, but vehicles that will launch initially are relatively small compared to medium-lift (e,g,, Long March 3C, H-IIA, Falcon 9, Atlas V) launch vehicles, not to mention heavy (e.g., Long March 5, Delta IV Heavy, Falcon Heavy) and super heavy-lift (e.g., Space Launch System, Starship) rockets.

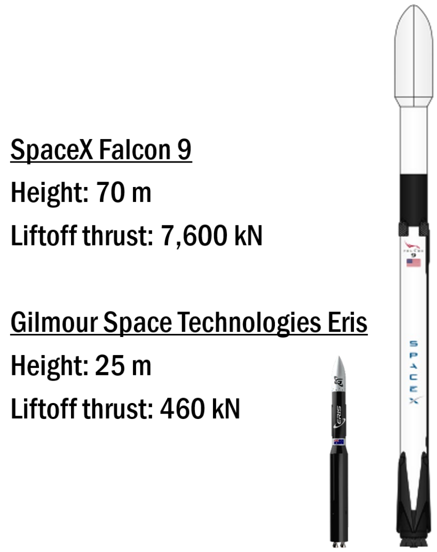

Figure 3. A comparison between the Gilmour Eris and the SpaceX Falcon 9 rockets.

3. ACOUSTICS OF AUSTRALIA-LAUNCHED ROCKETS

An increasing body of literature is improving our understanding of rocket noise physics. Much of this literature is described in a recent review article by Lubert *et al.*,[7] but more studies are appearing as additional measurements are made and modeling work performed. In this section, we discuss overall-sound-power level (OAPWL) estimates for rockets to be launched near-term from Australian spaceports and then discuss maximum overall-sound-pressure levels ($OASPL_{max}$) of the Eris rocket using two models.

Figure 4 shows OAPWL as a function of rocket mechanical power, W_m, which is calculated as one-half the product of the exhaust thrust multiplied by the exit velocity. Different dashed lines represent different radiation efficiencies, η, the ratio of the acoustic power to mechanical power. The base figure, created for the aforementioned review article by Lubert *et al.*,[7] contains data from historical rockets[16] as well as one possible fit[17] to the relatively scattered data, and a datapoint representing a Space Shuttle reusable solid-rocket motor (RSRM). The additional datapoints are all annotations to the figure and help provide context for Australia-launched rockets. First, Christian *et al.*[18] recently published a sound power and acoustic efficiency study on the T-7A, a recently developed supersonic trainer aircraft. At afterburner – the condition most closely resembling a rocket plume, albeit with lower temperatures and plume velocities (see Table I in Lubert et al.[7]) – the OAPWL (~173 dB re 1 pW) falls at the upper edge of the cluster of the smallest rockets used in SP-8072 model development. The acoustic efficiency of the aircraft was found to be $\eta \approx 0.6\%$, slightly more than the historically assumed value of 0.5% for rockets. This analysis also suggests that the highest-thrust afterburning tactical jet aircraft radiate OAPWLs in the 175-180 dB re 1 pW range. On the right portion of the plot are annotations for large orbital rockets. Ordered by W_m, they are Falcon 9[19], Delta IV Heavy[20], Saturn V,[21, 22, 23, 24] and NASA's Space Launch System.[24] These vehicles produce OAPWLs in the 195 – 204 dB re 1 pW range, with the Delta IV Heavy having the lowest radiation efficiency ($\eta \approx 0.2$ after ground effects are removed[25]) and the Saturn V having the greatest ($\eta > 0.6\%$). So where do the small orbital-class rockets found in Table I fall? Using the liftoff thrust provided in Table I and assuming an exit velocity of ~3 km/s for all engines and a range of efficiencies from $\eta = 0.25\%$ to $\eta = 0.6\%$, suggests OAPWLs around 179-186 dB re 1 pW for Australia-launched orbital rockets. The Daytona rocket is likely to be a few decibels louder than the highest-thrust military jet aircraft and Eris a few decibels more than that. This analysis puts reasonable bounds on radiated sound power when these rockets begin launching from Australian spaceports.

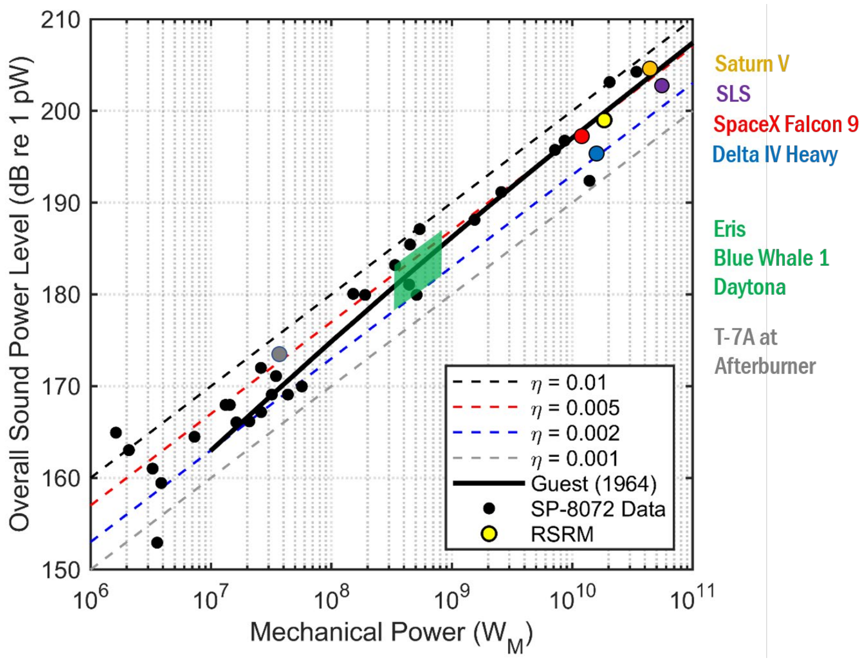

Figure 4. Overall sound power level as a function of rocket mechanical power. A figure based on one by Lubert et al.[7] has been annotated with additional data.

While understanding radiated sound power from a rocket is critical, it is sound pressure level that is observed locally. Here, we consider two approaches for obtaining the maximum observed overall sound pressure level $\mathrm{OASPL}_{\max}$ (also referred to as $L_{\max}$) for the Eris rocket. The first may be written as

$$\mathrm{OASPL}_{\max} = 10\,log_{10}\left(\frac{\eta W_m}{10^{-12} W}\right) - 10\,log_{10}(4\pi R^2) + Q_{\max}$$

$$= \mathrm{OAPWL} - 10\,log_{10}(4\pi R^2) + Q_{\max},$$

where η and W_m are as previously defined and R is the distance to the source. This model, first proposed by McInerny[26], combines three elements: estimating acoustic power from the mechanical power of the rocket by assuming an acoustic efficiency, accounting for spherical spreading (which gives the maximum overall-sound-pressure level for an equivalent monopole), and finally accounting for directionality by adding on a maximum-directivity factor $Q_{\max}$. Historically, an efficiency of $\eta = 0.5\%$ has been assumed with a maximum-directivity factor of $Q_{\max} = 8$ dB. Here, however, we will use $\eta \approx 0.25\%$ and $Q_{\max} = 5$ dB, which Mathews et al.[27] recently showed matched quite closely with Atlas V ground-based sound-pressure-level data that were corrected to for free-field conditions by subtracting 6 dB. After estimation of Eris free-field levels using the McInerny model and the Atlas V-suggested numbers, 6 dB is added to simulate near-ground levels over an acoustically hard surface.

A common distance at which to estimate levels is 100 nozzle exit diameters, D_e. Because Eris has $N = 4$ engines, an effective nozzle diameter, $D_{\mathrm{eff}} = D_e\sqrt{N} = 2D_e$, or ~1.2 m is used. At a distance of 100 D_{eff}, the $\mathrm{OASPL}_{\max}$ will be approximately 141 dB re 20 μPa. If extrapolated to 10 diameters using spherical spreading, levels will exceed 160 dB re 20 μPa. Because near-jet and rocket crest factors approach 20 dB,[23] peak levels within 10 m will exceed 180 dB re 20 μPa (20 kPa). These kinds of levels, with shock-containing waveforms with large pressure gradients, can cause damaging vibration of launchpad structures, payloads, and the rocket itself. To prevent incidence and reflection of these waves, launchpad design, including the use of water-based sound suppression systems, must be considered carefully.[7]

The second approach to determining $OASPL_{max}$ for Eris is to apply the model known as RUMBLE,[28] which takes a similar approach as Eq. 1, but accounts for spectral, curved trajectory, and some meteorological effects. Thus, RUMBLE is more appropriate for longer-range predictions than the above McInerny model. Because of its proximity to the Great Barrier Reef, an ecologically sensitive area, the Bowen Orbital Spaceport and surrounding region serves as an important case study. Calculations for an Eris-like rocket launched from the Bowen Orbital Spaceport over the Reef have been performed using RUMBLE 3.0. Because of the trajectory over the Reef, maximum levels along the closest portions of the Reef are predicted to be 70-75 dB re 20 μPa. Although RUMBLE can also provide A-weighted metrics, we are aware of ongoing work to evaluate and improve RUMBLE's performance in this regard. There is also concern as to the applicability of A-weighted levels in quantifying rocket-like noise impacts.[29]

The results in Fig. 5 suggest that launches will be distinctly audible along large portions of the Reef for this vehicle and trajectory. The noise will likely be primarily of low frequency (less than a few hundred hertz). Although the impedance change at an air-water interface reduces sound transmission into water,[30] above-water portions of the Reef can allow for direct structural transmission of these low-frequency sound waves beneath the water surface. Furthermore, even if waves evanesce beyond the critical angle, the low frequencies, long wavelengths, and near-surface coral structures could allow for reradiation of the rocket noise below the surface. Given the significant ecological challenges presently facing the Reef from different sources, these possible effects merit study.

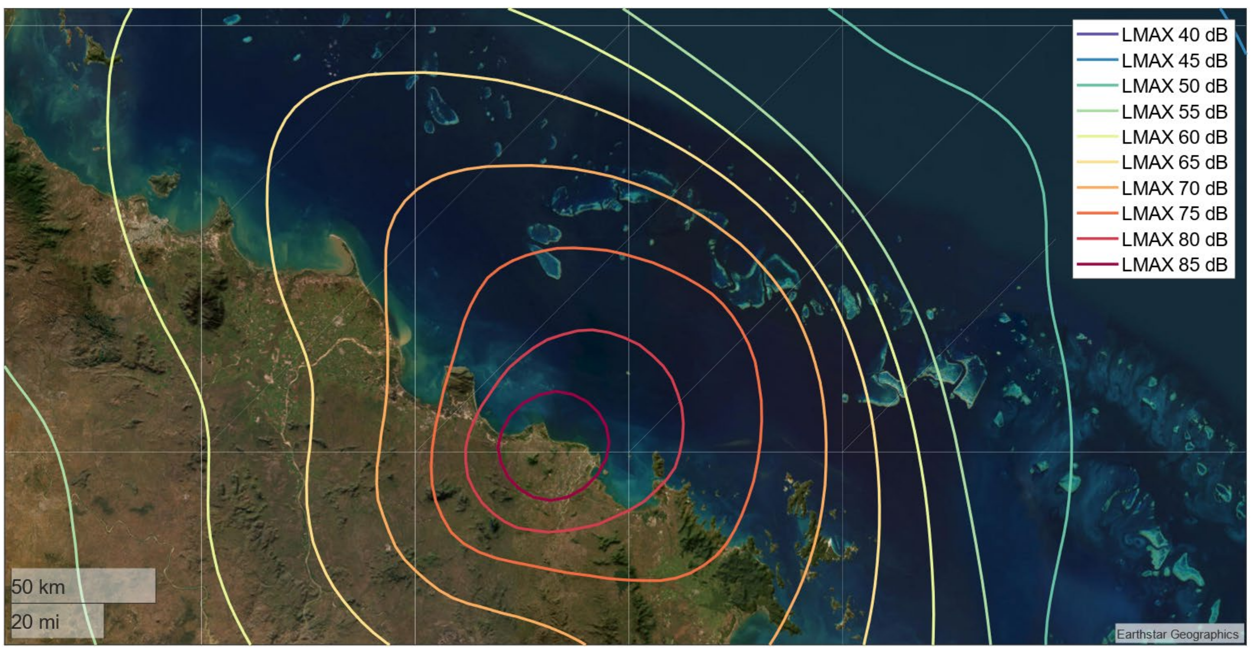

Figure 5. RUMBLE 3.0-predicted maximum overall sound pressure level for an Eris-like rocket launched over Australia's Great Barrier Reef.

4. LOOKING FORWARD

With a relatively new space agency and plans for new infrastructure and launch vehicles, Australia is taking strides to be an active player in the global orbital launch community. As vehicle launch cadence increases and larger, more capable vehicles come online, will launches from Australian soil create damaging vibrations around launchpads or harmful environmental noise impacts?[31] That is a complex question that depends on vehicle size and design, launch cadence, distance to structures, habitats, and communities, weather patterns, and other factors. Continued study of the multiple facets of generation, propagation, and reception of rocket noise will help find answers and improve our access to space, from Australia and worldwide.

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