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Spaceport Cornwall Carbon Impact Assessment

Main Report

Contents

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1. Executive summary

This report provides a rigorous assessment of the direct greenhouse gas (GHG) emissions from planned launches and ancillary activities associated with launch missions at the proposed Spaceport Cornwall between 2020 and 2030. In addition to direct emissions, the radiative forcing (RF) effects due to emissions at high altitude are also quantified given their importance in climate impacts of aviation activities and space missions.

Annual total GHG emissions of Spaceport Cornwall were estimated to grow gradually from 802 t CO_2e in 2021 to 1848 t CO_2e in 2025-2030 when RF effects at high altitude are excluded. When RF effects are considered, annual total GHG emissions more than double and would grow from 1,666 t CO_2e in 2021 to 4,239 t CO_2e in 2025-2030.

The magnitude of these emissions is relatively low compared with total CO_2 emissions in Cornwall. When RF effects are excluded, annual emissions from Spaceport Cornwall would be between 0.02% (year 2021) and 0.05% (year 2025 onwards) of Cornwall's total CO_2 emissions in 2016. When RF effects are considered, annual emissions from Spaceport Cornwall would be between 0.04% (year 2021) and 0.10% (year 2025 onwards) of Cornwall's total CO_2 emissions in 2016. Therefore, the proposed Spaceport Cornwall is not expected to impact on Cornwall's overall GHG emissions and efforts in combatting climate change.

The RF multipliers used in this report are based on the best current interpretation of the physical science with 'best practice' RF multipliers used throughout.

2. Introduction

Cornwall and Virgin Orbit are partnering to deliver a horizontal launch Spaceport at Cornwall Airport Newquay by 2020. This would become the world's first horizontal launch capability where human spaceflight, small satellite launch and passenger services are integrated. It is expected to bring a wide range of benefits to Cornwall, including, for example, jobs and economic growth. However, these benefits will need to be weighed against potential costs. One of the key environmental costs is the contribution towards anthropogenic climate change given the greenhouse gas (GHG)-intensive nature of space launches. In light of the continuing global fight against climate change and the recent declaration of a climate change emergency by the UK government and Cornwall Council, it is crucial to have a clear understanding of the GHG footprint of the proposed Spaceport Cornwall. This could help identify ways to reduce the climate impact of Spaceport Cornwall in the future.

This report was commissioned by Cornwall Council and aims to perform a rigorous assessment of the GHG emissions of planned launches from the proposed Spaceport Cornwall between 2020 and 2030. The next section will explain the method and data used to estimate the GHG footprint. Section 4 presents and discuss the results and finally Section 5 draws conclusions.

3. Method and Data

The scope of this assessment covers the direct GHG emissions from the launches and ancillary activities associated with launch missions. Emissions have been calculated annually between 2020 and 2030. All relevant GHGs (CO_2, CH_4 and N_2O) have been covered and converted into CO_2 equivalents (CO_2e) based on their global warming potential (GWP). The following information has been supplied by Virgin Orbit and is used in the calculations:

- The carrier aircraft will be Cosmic Girl – a modified Boeing 747-400 (41R) passenger aircraft manufactured in 2001 with a freighter configuration and no internal fittings. The range for Cosmic Girl per launch mission at 35,000 feet launch altitude is 800 nautical miles (nm) with an expected Jet A1 aviation fuel consumption of 77,000 lb;
- The rocket used will be the LauncherOne system with a weight of 57,000 lb and an expected RP-1 rocket fuel consumption of 15,760 lb per launch (14,000 on first stage and 1,760 on second stage);
- The ancillary activities associated with launch missions that will be considered include UK test flights, rocket and carrier aircraft transit while excluding the following: abortive launch missions; US test programme; launch failures and rocket flight terminations; rocket manufacture; retrieval of 1st of 2nd stage rocket stages; range operations; individual launch personnel travel; US based transport; fuel transport in UK and liquid oxygen manufacture; and RP1 and Jet A1 refinement/processing;

- UK test flight range is assumed to be 200 nm (two 100-nm test flights) per launch;
- Aircraft round-trip transit distance is assumed to be 11,000 miles between Long Beach, USA and Cornwall Airport Newquay;
- Rocket transit distance is assumed to be 7,400 nm per year and the number of rockets transported in a particular year is the same as the number of launches in that year. Rockets will be without fuel when transported and weigh 41,240 lb each (57,000 – 15,760);
- The planned number of launches would be 0, 1, 3, 4, 5, 8 and 8 in 2020, 2021, 2022, 2023, 2024, 2025 and 2026, respectively. The number of launches is projected to stay at 8 between 2027 and 2030.

Apart from the information above, emission factors for the Jet A1 aviation fuel and RP-1 rocket fuel, fuel consumption rates for the aircraft and rocket transits have been accessed from the most suitable sources. Direct GHG emission factors for Jet A1 are taken from the UK Government GHG Conversion Factors [1] for aviation turbine fuel (see Table 1). These factors cover three main types of GHGs, i.e., CO_2, CH_4 and N_2O and are all converted to CO_2e based on their global warming potential (GWP). GHG emission factors for RP-1 cannot be found in publicly available literature. However, there are reports that suggest RP-1 is very similar to Jet A1 and the same emission factors can be used [2].

In addition to direct emissions, radiative forcing (RF) effects due to emissions at high altitude have also been quantified. RF is the net change in the energy balance of the Earth system due to some imposed perturbation, usually expressed in watts per m^2 averaged over a particular period of time. It is effectively a measurement of the capacity of the emitted GHG, and/or other forcing agents, to affect the energy balance and thereby defines the contribution of the activity to climate change. The GWP methodology used to convert emissions of GHGs into CO_2e is based on the RF of GHGs relative to that of CO_2. More details of RF and GWP can be found in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [3].

It has long been recognised that emissions at high altitude in the stratosphere have higher RF (and hence GWP) than emissions at lower altitudes or ground level and therefore need to be appropriately accounted for given the expected increase in aviation and space launch activities [2–6]. However, there are significant uncertainties in the magnitude of these effects for different emissions such as CO_2, water vapour and black carbon soot at high altitude. In order to take into account this RF effect, different studies calculated the so-called radiative forcing index (RFI) factor that can be multiplied by the direct CO_2 emissions at high altitude (e.g., from aviation). The UK Government GHG Conversion Factors [1] applies a RFI factor of 1.9 for aviation CO_2 emissions, i.e., a 90% increase to the direct CO_2 emissions. A recent study [7] systematically reviewed the state of the art approaches to the accounting for RF effects of aircraft emissions and recommended a RFI factor of 2 for total direct aircraft CO_2 emissions or 5.2 for emissions in the higher atmosphere.

This report will adopt two different approaches. The first approach is to only account for the direct GHG emissions from the Spaceport activities excluding the RF effects at high altitude. The second approach is to apply a RFI factor of 2 to the total direct CO_2 emissions from Cosmic Girl (Jet A1) as the split between emissions at higher and lower atmosphere is unavailable and a RFI factor of 5.2 to the total direct CO_2 emissions from LauncherOne (RP-1) as they will only be at higher atmosphere. The emission factors for these two approaches are listed in Table 1.

Table 1. GHG emission factors for Jet A1 and RP-1 used in this report (kg CO_2e/kg fuel)

	Total (CO_2e)	CO_2	CH_4	N_2O
Direct emission factors without RF for Jet A1 & RP-1 (Approach 1)	3.18137	3.14967	0.00191	0.0298
Emission factors with RF for Jet A1 (Approach 2)	6.33105	6.29934	0.00191	0.0298
Emission factors with RF for RP-1 (Approach 2)	16.40999	16.37828	0.00191	0.0298

Some other assumptions made include the following:

- Fuel (Jet A1) consumption rate of Cosmic Girl (no payload) for the transit between Long Beach, USA and Cornwall Airport Newquay and test flights in the UK is estimated to be 11.6 kg/km based on information available in the technical specifications of Boeing 747-400ER with General Electric engines and a 240,310 L fuel capacity [8];
- Transoceanic ships will be used for rocket transit from USA to Cornwall Airport Newquay. Marine fuel oil consumption rate of the ships is assumed to be 0.0025 kg/t-km based on information available in the ecoinvent database [9]. The GHG emission factor for marine fuel oil is 3.15955 kg CO_2e/kg fuel based on the UK Government GHG Conversion Factors [1].

4. Results and discussions

The results for annual GHG emissions from different activities related to the space launches are presented in Figure 1 and Table 1. When using Approach 1 where RF effects at high altitude are excluded, annual total GHG emissions grow gradually from 802 t CO_2e in 2021 to 1848 t CO_2e in 2025 and stay at that level. Cumulative emissions are 8,250 and 15,643 t CO_2e by end of 2026 and 2030, respectively. Shares of the launch emissions (LauncherOne and Cosmic Girl) in the total also gradually increase from 17% in 2021 to 58% between 2025 and 2030 as the number of launches increases. Emissions from Cosmic Girl dominate the launch emissions, representing 83% of the total.

When using Approach 2 where RF effects are taken into account, annual total GHG emissions more than double, growing from 1,666 t CO_2e in 2021 to 4,239 t CO_2e in 2015-2030. Cumulative emissions are 18,448 and 35,404 t CO_2e by end of 2026 and 2030, respectively. Launch emissions now account for 20-64% of the total and emissions from LauncherOne are slightly higher than those from Cosmic Girl. In both cases contributions from rockets transit and UK test flights (ancillary activities) to the total emissions are relatively small.

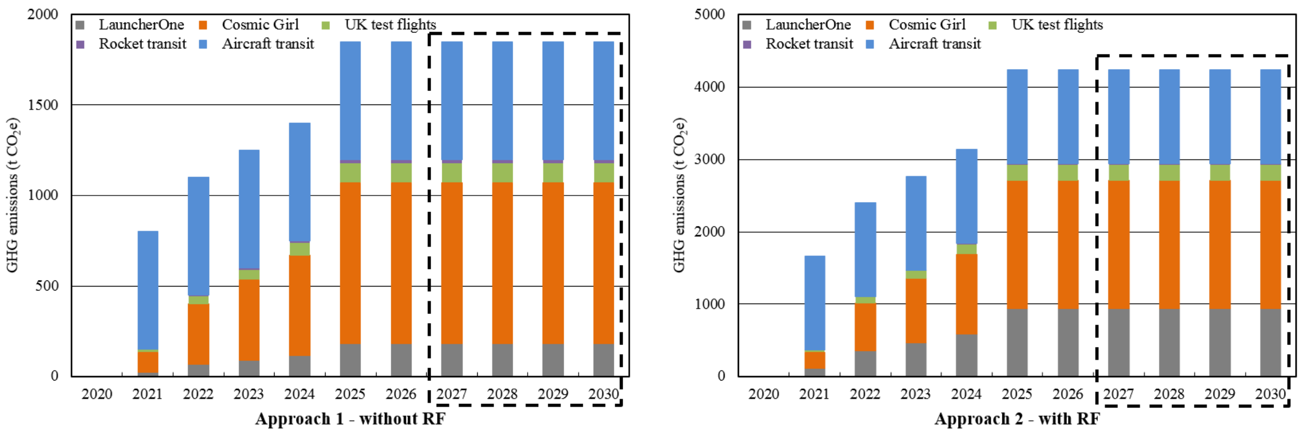

Figure 1. Annual GHG emissions from different activities related to space launches at Spaceport Cornwall without (left) and with (right) RF effects at high altitude (number of launches in dashed lines is projected)

Table 1. GHG emissions from different activities related to space launches at Spaceport Cornwall without and with RF effects at high altitude

	Known							Projected			
	2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Approach 1 - without RF											
Total launch emissions (t CO_2e)	**0**	**134**	**402**	**535**	**669**	**1071**	**1,071**	**1,071**	**1,071**	**1,071**	**1,071**
LauncherOne	0	23	68	91	114	182	182	182	182	182	182
Cosmic Girl	0	111	333	444	556	889	889	889	889	889	889
Total ancillary emissions (t CO_2e)	**0**	**668**	**699**	**715**	**731**	**778**	**778**	**778**	**778**	**778**	**778**
UK test flights - Cosmic Girl	0	14	41	55	68	109	109	109	109	109	109
Rocket transit - LauncherOne	0	2	6	8	10	16	16	16	16	16	16
Aircraft transit - Cosmic Girl	0	652	652	652	652	652	652	652	652	652	652
Total annual emissions (t CO_2e)	**0**	**802**	**1,101**	**1,250**	**1,400**	**1,848**	**1,848**	**1,848**	**1,848**	**1,848**	**1,848**
Cumulative known emissions (<2026)							8,250				
Cumulative projected emissions (<2030)											15,643
Approach 2 - with RF											
Total launch emissions (t CO_2e)	**0**	**338**	**1,015**	**1,354**	**1,692**	**2,707**	**2,707**	**2,707**	**2,707**	**2,707**	**2,707**
LauncherOne	0	117	352	469	587	938	938	938	938	938	938
Cosmic Girl	0	221	663	884	1106	1769	1,769	1,769	1,769	1,769	1,769
Total ancillary emissions (t CO_2e)	**0**	**1,327**	**1,385**	**1,415**	**1,444**	**1,531**	**1,531**	**1,531**	**1,531**	**1,531**	**1,531**
UK test flights - Cosmic Girl	0	27	81	109	136	217	217	217	217	217	217
Rocket transit - LauncherOne	0	2	6	8	10	16	16	16	16	16	16
Aircraft transit - Cosmic Girl	0	1298	1298	1298	1298	1298	1,298	1,298	1,298	1,298	1,298
Total annual emissions (t CO_2e)	**0**	**1,666**	**2,401**	**2,768**	**3,136**	**4,239**	**4,239**	**4,239**	**4,239**	**4,239**	**4,239**
Cumulative known emissions (<2026)							18,448				
Cumulative projected emissions (<2030)											35,404

To put these results into context, annual GHG emissions from Spaceport Cornwall as a percentage of Cornwall's total CO_2 emissions in the year 2016 (2,821 thousand tonnes [10]) are shown in Table 2. This percentage is between 0.02% (year 2021 – Approach 1) and 0.10% (year 2030 – Approach 2).

Table 2. Annual GHG emissions from Spaceport Cornwall as a percentage of Cornwall's total CO_2 emissions in the year 2016

	Known							Projected			
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Without RF		0.02 %	0.03 %	0.03 %	0.03 %	0.05 %	0.05 %	0.05 %	0.05 %	0.05 %	0.05 %
With RF		0.04 %	0.06 %	0.07 %	0.08 %	0.10 %	0.10 %	0.10 %	0.10 %	0.10 %	0.10 %

It should be noted that there are uncertainties with the results and therefore they need to be interpreted carefully. The key uncertainty is the RF effects in Approach 2. This is an area that is still under extensive scientific research and lacks consensus. This report has adopted the most appropriate 'best practice' multiplication factors that are available in the current literature [7]. However there is the possibility that these multipliers could potentially change as the scientific understanding of the RF effects of emissions at high altitude advances.

In addition some parameters such as the fuel consumption rates are supplied directly by Virgin Orbit or estimated based on the best available information. These could potentially be refined in the future when actual operation data becomes available.

5. Conclusions

This report presents findings from a rigorous assessment of the GHG footprint of planned launches from the proposed Spaceport Cornwall between 2020 and 2030. Annual total GHG emissions were estimated to grow gradually from 802 t CO_2e in 2021 to 1,848 t CO_2e in 2025-2030 when RF effects at high altitude are excluded, with cumulative emissions of 8,250 and 15,643 t CO_2e by end of 2026 and 2030, respectively. When RF effects are considered, annual total GHG emissions more than double and would grow from 1,666 t CO_2e in 2021 to 4,239 t CO_2e in 2025-2030, with cumulative emissions of 18,448 and 35,404 t CO_2e by end of 2026 and 2030, respectively.

The magnitude of these emissions is relatively low compared with total CO_2 emissions in Cornwall. When RF effects are excluded, annual emissions from Spaceport Cornwall would be between 0.02% (year 2021) and 0.05% (year 2025 onwards) of Cornwall's total CO_2 emissions in 2016. When RF effects are considered, annual emissions from Spaceport Cornwall would be between 0.04% (year 2021) and 0.10% (year 2025 onwards) of Cornwall's total CO_2 emissions in 2016. It should be noted that results including RF effects are highly uncertain as the science base for the RF effects of emissions at high altitude still needs to be improved. Overall, the proposed Spaceport Cornwall is not expected to impact significantly on Cornwall's total GHG emissions and efforts in combatting climate change.

6. References

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7. Supporting material

An Excel file is attached to this report, detailing all the assumptions and calculations.