

Presentation at 'Linking militarised space and the climate crisis' webinar, 2 October 2021 – organised by the Global Network Against Weapons and Nuclear Power in Space

Spaceflight – a few basics Uncrewed/ robotic missions – main aims: Telecommunications Monitoring of Earth's environment Military purposes, including monitoring, telemetry for military operations Studying outer space Crewed/ human missions – main aims: Research, including some of the above Space exploration Public relations for science Tourism What is essential?

- Telecommunications includes navigation for shipping, aviation
- Monitoring of Earth's environment includes weather, climate, oceans, land, pollution etc
- Some military monitoring is essential for arms control/ disarmament treaties
- Some military programmes are only useful for war-fighting and other military operations
- Growing interest in development and deployment of space weapons
- Studying outer space includes Sun, Moon, planets, asteroids, comets, stars etc
- What is essential? Particular questions over human spaceflight

[image credit: NASA]

Climate issues

- Spaceflight very energy intensive per launch
 - Especially heavy payloads (incl. humans) and long distance missions
- Carbon emissions per tonne of rocket fuels generally high
 - Liquid hydrogen is over 6 times higher than petrol/gasoline
- Additional heating effects due to emissions in stratosphere
 - Including water vapour and black carbon
- To minimise climate impacts, need to minimise:
 - Number of launches
 - Weight of launches (often related to destination)



- Carbon emissions per tonne of rocket fuels generally higher than petrol (gasoline)
- Liquid hydrogen over 6 times higher than petrol due to very high energy consumption during production
 Calculations based on data in: Berners-Lee M (2020). How bad are bananas?
 Profile books. p256
- To liquify hydrogen it needs to be cools below -253C at atmospheric pressure
- For discussion of stratospheric heating effects, see: Chapman P (2016). https://www.sgr.org.uk/resources/flights-sense-how-spacetourism-could-alter-climate-february-2016

[image: Saturn V launch; image credit: NASA]

organisations	Country	Launch vehicle	Propellants	
Roscosmos/ RSC Energia	Russia	Soyuz 2	Refined kerosene/ liquid oxygen	
SpaceX/ NASA	USA	Falcon 9	Refined kerosene/ liquid oxygen	
Blue Origin	USA	New Shepard 4	Liquid hydrogen/ liquid oxygen	
Virgin Galactic	USA	SpaceShipTwo	HTPB/ N2O	
CASC	China	Long March 2	UDMH/ NTO	
NASA	USA	Space Launch System	Liquid hydrogen/ liquid oxygen PBAN/ APCP	
 Space Launch S Moon (1st crewe Other crewed s Other corporati Space Adventur Billionaire invol 	ystem part of N ed flight due in pace-craft are u ons involved in es (using Soyuz vement: Space>	ASA's Artemis programme, 2023) Inder development clude: Boeing/ United Laur :) < (Musk); Blue Origin (Bezo	sending humans back to nch Alliance; Sierra Nevada; s); Virgin Galactic (Branson)	

- Chemicals: Refined kerosene 'RP-1' (Rocket Propellant 1); HTPB Hydroxylterminated polybutadiene; N2O – Nitrous oxide; UDMH - Unsymmetrical dimethylhydrazine; NTO - nitrogen tetroxide; PBAN - Polybutadiene acrylonitrile; APCP - Ammonium perchlorate composite propellant
- Soyuz 2 also uses UDMH/ NTO in 'Upper stage' outside Earth's atmosphere
- Soyuz 2/ Falcon 9 launch: crew and supplies to International Space Station; satellites; and (from 2021) space tourists
- New Shepard 4/ SpaceShipTwo mainly used for space tourists
- Long March 2 used for crew and supplies to new Chinese space station
- Sources:

https://en.wikipedia.org/wiki/Human_spaceflight

https://en.wikipedia.org/wiki/Soyuz-2

https://spaceflight101.com/spacerockets/soyuz-2-1a/

https://en.wikipedia.org/wiki/Falcon_9

https://spaceflight101.com/spacerockets/falcon-9-ft/

https://en.wikipedia.org/wiki/New_Shepard

https://en.wikipedia.org/wiki/SpaceShipTwo

https://spacenews.com/shenzhou-12-docks-with-tianhe-space-station-module/

https://spaceflight101.com/spacerockets/long-march-2f/

http://english.spacechina.com/n16421/index.html https://en.wikipedia.org/wiki/Artemis_program https://en.wikipedia.org/wiki/Space_Launch_System



- Numerous launches including both crew and supply-only missions
- For summary of Artemis, see: https://en.wikipedia.org/wiki/Artemis_program

[Image credit: NASA]

Carbon emissions of crewed space-craft

Organisations	Launch vehicle	No. of crew	Carbon emissions per launch (tCO2e)	Carbon emissions per person (tCO2e)		
Roscosmos/ RSC Energia	Soyuz 2	3	290	95		
SpaceX/ NASA	Falcon 9	4	510	125		
NASA	Space Launch System	4	3,660	915		
Votes • Calculations based on data from Spaceflight101.com, NASA and Berners-Lee (2020) • tCO2e – tonnes of carbon dioxide equivalent • Figures for carbon emissions are rounded						

- Estimates for carbon emissions have significant uncertainty, but are conservative
- Virgin Galactic carbon emissions are significantly less than competitors because it does not technically reach 'outer space' but has other climate/ environmental impacts
- Soyuz example is Soyuz MS-20 scheduled for Dec 2021 space tourism flight
- Falcon 9 example is Inspiration 4 flew in Sep 2021 space tourism flight
- Space Launch System (SLS) example is Artemis 1 due for launch in 2023
- No estimates for New Shepard or SpaceShipTwo due to lack of publicly available data
- Estimates for carbon emissions have significant uncertainty, but are conservative see simplifications below
- Data/ calculations:

Carbon emissions factors: refined kerosene (RP-1): 3.75 tCO2e/t; liquid hydrogen (LH2): 25 tCO2e/t; liquid oxygen (LOX): 0.12 tCO2e/t (Berners-Lee, 2020, p255-6) Soyuz 2 – RP-1: relevant mass: 70 t; LOX: relevant mass: 194 t Falcon 9 – RP-1: relevant mass: 124 t; LOX: relevant mass: 162 t SLS – LH2: relevant mass: 142 t; LOX: relevant mass: 847 t

• Simplifications:

For RP-1, mass of 1st stage fuel only considered as GHG emissions from upper stages outside atmosphere; lifecycle emissions of this mass also included (some 1st stage emissions will be high enough not to have much heating effect – this is likely to be a small proportion)

For LH2, total mass of fuel considered as emissions are due to production of fuel not

combustion (although transport, storage and infrastructure not included) For LOX, total mass of oxidiser considered as emissions are due to production of fuel not combustion (although transport, storage and infrastructure not included) PBAN/ APCP related emissions not included (combustion emissions outside atmosphere/ no data on lifecycle emissions)

Additional stratospheric heating effects of water vapour and other gases not considered – but could be large

Carbon emissions due to manufacture/ raw materials of rocket etc not included Carbon emissions per person includes essential crew (e.g. pilot) – hence the figure would be higher 'per tourist'

• Sources:

https://spaceflight101.com/spacerockets/soyuz-2-1a/

https://en.wikipedia.org/wiki/Soyuz_MS-20

https://spaceflight101.com/spacerockets/falcon-9-ft/

https://en.wikipedia.org/wiki/Inspiration4

https://en.wikipedia.org/wiki/Space_Launch_System

Berners-Lee M (2020). How bad are bananas? Profile books. p150-2, p255-6.

https://en.wikipedia.org/wiki/SpaceShipTwo

Chapman P (2016). https://www.sgr.org.uk/resources/flights-sense-how-space-

tourism-could-alter-climate-february-2016



- US Space Force: https://en.wikipedia.org/wiki/United_States_Space_Force
- Draft PAROS treaty Treaty for the Prevention of an Arms Race in Outer Space see:

NTI (2021). https://www.nti.org/learn/treaties-and-regimes/proposed-preventionarms-race-space-paros-treaty/

[image credit: US DoD]



- Annual carbon footprint of 1 UK citizen data from: WWF (2020). Carbon Footprint: Exploring the UK's Contribution to Climate Change. <u>https://www.wwf.org.uk/sites/default/files/2020-04/FINAL-WWF-</u> <u>UK Carbon Footprint Analysis Report March 2020%28003%29.pdf</u>
- Sustainable lifestyle carbon footprint in 2030 data from: IGES (2019). 1.5-Degree Lifestyles. https://www.iges.or.jp/en/pub/15-degreeslifestyles-2019/en

[image credit: WWF]



Source: Oxfam (2015)

https://policy-practice.oxfam.org/resources/extreme-carbon-inequality-why-the-paris-climate-deal-must-put-the-poorest-lowes-582545/



- UN Secretary General quote: https://www.bbc.co.uk/news/science-environment-58130705
- Intergovernmental Panel on Climate Change (2021). 6th Assessment Report. https://www.ipcc.ch/assessment-report/ar6/
- UK fair share used in 3.3y Chapman I (2021). https://www.sgr.org.uk/resources/uk-s-share-global-carbonbudget-will-be-used-just-over-3-years

[image credit: iStockphoto]



• Example of essential military mission – monitoring for disarmament treaties

[image credit: Emily Heath]